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Proceedings of the American Society of Civil Engineers

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Note.—Part 2 of this Journal is the 1960-43 Newsletter of the Irrigation and Drainage Division.

DISCUSSION

Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

VORTEX TUBE SAND TRAP[a]

By A. R. Robinson[1]

SYNOPSIS

Tests were made on a device that can be used for the removal of large sediments from canals. This material must be traveling as bed load in order to be trapped by the tube. Data from several investigations have been combined in order to develop the general design information that is presented.

INTRODUCTION

The accumulation or movement of gravel and sand in irrigation, power, and municipal canals presents problems that are usually common in the operation of water conveyance systems. When coarse sediments enter the canal through diversion structures or because of unstable channel conditions and are eroded from the canal itself, many difficulties may arise. Some of the problems encountered are: (1) the depositing of material in some reaches of the channel thereby reducing the carrying capacity and making frequent cleaning necessary, (2) gravel or sand entering the turbines in a power canal, (3) municipalities requiring the construction of elaborate desilting facilities for removal

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[a]Joint contribution from Soil and Water Conservation Research Div., Agric. Research Service, U.S. Dept. of Agric., and Colorado Agric. Experiment Sta., Ft. Collins, Colo.

[1]Agric. Engr., Western Soil and Water Mgt. Research Branch, U.S. Dept. of Agric., Agric. Research Service, Soil and Water Conservation Research Div., and Colo. Agric. Experiment Sta., Ft. Collins, Colo.

of this material, and (4) materials carried in irrigation canals ultimately depositing in a detrimental manner on farmlands when the water is applied.

A properly designed diversion works can exclude a portion of the material before it enters the channel. However, many diversion works were constructed before much was known about proper design for excluding or bypassing sediment. Many diversion dams act as sediment traps so that much more material than is necessary enters the canals. An overabundance of this material usually causes difficulties and must be removed.

In the case of earth canals, the channels should be designed to remain as stable as possible for all conditions of flow. Here again, a lack of knowledge of proper design has resulted in many unstable situations. Material is eroded in certain reaches to be deposited at others. Canals that infrequently act as floodways may also catch material that must later be removed.

Successful design of a device for extracting sediments involves many engineering aspects. Some of these are stable channel theory, mechanics of sediment transport, and the hydraulic principles governing operation of the device as well as structural design. For this problem, interest in sediment transport is confined to that material near the bed.

Extensive studies have been conducted in India on development of sediment excluders and extractors. In the United States, the development of the vortex tube sand trap as an extractor has been noteworthy. Pioneer development of this device was made by Carl Rohwer and Ralph L. Parshall. Considerable experimental work was done to develop the device for specific installations. However, general design criteria to assist field engineers in designing the vortex tube has been lacking.

This report summarizes the results of a study initiated to correlate the results of past studies and to conduct further investigations for developing needed design information.

Notation.—The letter symbols adopted for use in this paper are defined where they first appear, in the illustrations or in the text, and are arranged alphabetically, for convenience of reference, in Appendix I.

REVIEW OF LITERATURE

Sediment ejectors usually consist of slots or apertures in the bed of a canal through which coarser material moving as bed load can be removed along with a small quantity of the flow. Uppal (14)[2] described a device used in India to remove bed load that consisted of a series of small tunnels facing into the flow. The height of these tunnels was about one-fourth the depth of water in the canal. Flow entering the tunnels along with bed load was diverted out of the canal; also described was the use of large tunnels that passed under the canal proper. Slots were provided in a canal structure for larger sand fractions to drop through into the lower tunnel. One end of the tunnel was blocked. The other end was provided with a gate that, when opened, caused the tunnel to function as an ejector discharging into a cross drainage system.

Tests of the vortex tube sand trap along with a riffle deflector device were first reported by Parshall (8). The vortex tube sand trap was described as a tube with an opening along the top and placed in the bed of a canal at an angle of about 45° to direction of flow. As flow passed over the opening, a spiral

[2]Numerals in parenthesis—thus; (1)—refer to corresponding items in the Appendix, Bibliography.

motion was set up within the tube. Material traveling along the canal bed was drawn or dropped into the tube and carried to an outlet at which it was discharged into a return channel. The device was observed to be very effective in removing large material even to the size of cobblestones. The riffle deflector sand trap was described as consisting of a series of curved metal plates, each the shape of the quadrant of a circle fastened to the channel floor. Bed load was caused to move to one side of the channel at which it was removed through an opening. A combination of riffles and tubes was also tested with considerable success.

Rohwer, et al. (10) reported the results of tests conducted on vortex tubes installed in channels 8 ft and 14 ft wide. The tubes used were 4 in. and 6 in. in diameter set at various angles to the flow. Conclusions from these tests were given as: (1) the tubes were most active when the depth of water in the channel was slightly less than critical; (2) straight or tapered tubes were equally efficient in removing sand; (3) angle of tube for angles less than 90° to the direction of flow had little effect on efficiency; (4) efficiencies of trapping were conspicuously better when elevations of the upper and lower lips were the same; (5) the tubes would remove from 70% to 90% of bed load carried by the flume; (6) tubes in a channel that was 8 ft wide seemed to be more efficient in sand removal than ones installed in a channel 14 ft wide; and (7) when the Froude number of the flow immediately upstream from the tube exceeded 1.3 a considerable amount of sand and gravel was thrown out of the tube and reentered the channel.

The amount of flow from the tube was regulated for some of these tests. This was accomplished by controlling the water level at the tube outlet so that the percentage of flow removed could be varied. It was found that the wasted flow could be reduced by 40% to 50% with a corresponding smaller reduction in the trapping efficiency.

Measurements of velocity of translation and rate of rotation of the flow within the vortex tube were attempted. The maximum translation velocity was found to be approximately 0.4 times the mean velocity in the channel. Because of the number of variables introduced into the study, it was not possible to determine the relationship of translation velocity and rotation to other factors.

Further tests on the vortex tube are also reported by Rohwer (11). For these tests, tube shape was varied as well as size of sand. The tubes were installed at an angle of 45°. By testing a number of tubes a shape was found that gave the highest trapping efficiency. This efficiency varied with the size of material, being near 90% for material with a median diameter of 1.75 mm and 45% for 0.38 mm median diameter sands. These efficiencies were nearly constant for a range in Froude numbers from 0.4 to 1.3 (velocities 2.3 to 7.9 fps). The percentage of total flow removed by the tube varied from 3.8 to 13.0.

The amount of flow from the tube was also controlled in a limited number of tests. It was found that a reduction of tube discharge of 40% to 50% caused only a slight decrease in trapping efficiency. In both series of tests reported by Rohwer (10), (11) the sand was instantaneously dumped into the channel; thus, a constant rate of sediment inflow was not maintained.

Parshall (9) stated that the optimum action of the vortex tube occurred when the water passing over the lip was at or near critical velocity. He also stated that field installations of the device had been both successful and unsuccessful. In installations that were ineffective it was noted that the velocity in the canal was low and the tube was set below channel grade. Trapping efficiencies of 90% were claimed for the device when operating properly.

A tube 0.2 ft in diameter with one-quarter of the circumference cut away and installed in a flume 2 ft wide was studied by Koonsman (3), (4). The sand used for the tests had a size range of 0.4 to 1.1 mm with a median diameter of 0.7 mm. Concentrations of sand ranged from 0.09 to 0.68 in percent by weight. Velocity of flow varied from 1.3 to 5.5 fps while depth ranged from 0.2 ft to 0.6 ft (Froude number, $\mathbf{F}$, 0.5 to 1.5). The elevation of the downstream lip was varied relative to the upstream one. Results from these tests showed that: (1) highest trapping efficiencies (92%) were noted near a Froude number of 1.0; (2) efficiencies decreased as the depth of flow increased; (3) efficiencies decreased as concentration was increased beyond a certain point depending also on the depth of flow; (4) optimum operation was noted when the lips were at the same elevation; and (5) percentage of flow removed from the tube varied from 2.7% to 15.5% depending on velocity and depth of flow over the tube. The reason given for the apparent decrease in efficiency with increasing depth was that greater quantities of sediment were being moved and more of this material was in suspension at the greater depths.

Model studies of sediment control structures for diversion dams have been reported by Martin and Carlson (7). Included in the studies of the Republic diversion dam was a vortex tube that was installed upstream from the radial gate at the headworks. Various arrangements of guide walls alone and in combination with the vortex tubes were tried in order to exclude sand from the canal. The inclusion of the vortex tube in the model design gave the greatest improvement in exclusion of any individual change. A unique innovation of the design was the installation of a tapered horizontal vane over the vortex tube. The tapered vane increased the velocity directly over the tube causing the vortex in the tube to be more active that in turn increased its ability to move sand.

In a design study by Ahmad (1), the vortex type ejector was found to be superior to the frontal type and was, therefore, preferable to the common ones used in Pakistan. The vortex type gave greater efficiencies at less discharge extractor ratios (percent of total flow removed) under similar operating conditions. The following recommendations were made regarding the design of the vortex tube.

(1) The structure should be designed so that the Froude number of flow at the tube is equal to 0.8.

(2) Diameter of the tube should be equal to water depth in the channel at a Froude number equal to 0.8.

(3) The two lips of the opening slit should be at the same elevation.

(4) Opening of the slit should be one-sixth of tube circumference.

(5) Under conditions of heavy silt concentration, a long tube may not work efficiently. In this case, shorter tubes should be used, each equipped with an independent discharge pipe.

Review of past studies indicates that the vortex tube type of sand trap has been found to be superior to other types of sediment ejectors. The following design features are indicated based on findings of previous investigators.

(1) The Froude number of the flow in the section containing the vortex tube should be near 1.0.

(2) Amount of flow removed by the tube depends on slot opening as well as depth and velocity of flow. An average extractor ratio of about 10% was indicated.

(3) The shape of tube was not particularly important as long as area was sufficient and shape such that sediment would not escape from the tube once it had entered. Rohwer (11), however, developed and tested a particular shape that had almost constant efficiencies regardless of rate or depth of flow.

(4) Efficiency of trapping increases as size of material increases.

(5) Straight tubes performed equally as well as tapered ones.

(6) There seems to be a limiting length of tube for optimum operation.

(7) The angle of tube should be in the range of 45° to 65° from the direction of flow.

ANALYSIS OF THE PROBLEM

As stated previously, the successful design of a bed load extractor must necessarily consider stable channel design, the mechanics of sediment transport, and the hydraulic principles governing the operation of the device.

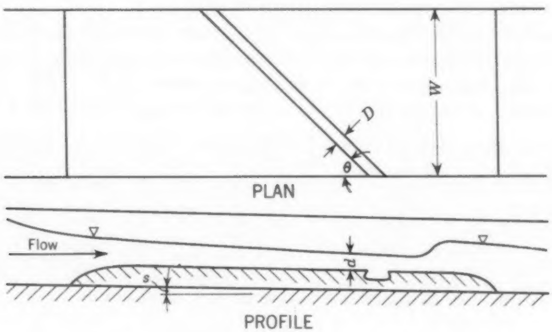


FIG. 1

Dimensional Analysis.—In order to group the pertinent variables involved in the operation of a vortex tube and to arrange these variables for a systematic approach to the problem, dimensional analysis can be used. By using the dimensionless parameters that result, a study covering a maximum range of operating conditions can be made.

Some of the variables describing the physical features of the vortex tube are shown in Fig. 1.

The variables describing the channel and tube are width of opening, D; the difference in upstream and downstream lip elevations, P; the contraction ratio between the channel and section containing the vortex tube, Z; the width of vortex tube section, W; the slope of channel, s; the shape of tube (may also describe relative area), λ; and the angle of tube to direction of flow, θ.

Variables describing the flow are the depth of flow upstream from tube, d; the mean velocity of flow immediately upstream from tube, V; the water discharge through tube, Q_T; the total sediment discharge through channel, G; and the sediment discharge through the tube, G_T.

The sediment may be described by the density, ρ_s; the size of sand fraction, d_s; and the fall velocity, ω.

Variables describing the fluid are the dynamic viscosity, μ; the density, ρ; and the specific weight of fluid, γ. The general relationship that exists between the variables is

$$\phi_1 \left(D, P, Z, W, S, \lambda, \theta, d, \overline{V}, Q_T, G, G_T, \rho_s, \omega, d_s, \mu, \rho, \gamma\right) = 0. \qquad (1)$$

Choosing $\overline{V}$, ρ and D as repeating variables and combining yields

$$\phi_2 \left(\frac{P}{D}, Z, \frac{W}{D}, s, \lambda, \theta, \frac{d_u}{D}, \frac{Q_T}{\overline{V}\ D^2}, \frac{G}{\overline{V}\ D^2}, \frac{G_T}{\overline{V}\ D^2}, \frac{\rho}{\rho_s}, \frac{\omega}{\overline{V}}, \frac{d_s}{D}, \frac{\overline{V}\ D\ \rho}{\mu}, \frac{\overline{V}}{\sqrt{g\ D}}\right) = 0 \ldots (2)$$

By replacing d_u for D and W d_u for D^2 in the flow parameters, Eq. 2 can be written as

$$\phi_3 \left(\frac{P}{D}, Z, \frac{W}{D}, s, \lambda, \theta, \frac{d}{D}, \frac{Q_T}{Q}, \frac{G}{Q}, \frac{G_T}{Q}, \frac{\rho}{\rho_s}, \frac{\omega}{\overline{V}}, \frac{d_s}{D}, \frac{\overline{V} d \rho}{\mu}, \frac{\overline{V}}{\sqrt{g\ d_u}}\right) = 0 \ \ldots . (3)$$

with Q representing the quantity of flow, $\overline{V}$ W d_u.

On the basis of known relationships, and from previous studies, certain delimitations can be made to reduce the number of variables involved. Some terms can be eliminated from Eq. 3 for the present study. The term s can be eliminated because it is related to velocity and depth, θ because it will be constant at 45° from direction of flow, $\frac{\rho}{\rho_s}$ because it will be essentially constant for sand and water, and $\frac{\overline{V}\ d_u\ \rho}{\mu}$ (Reynolds number **R**) because it should be of minor importance in a problem of this nature. The parameter Z will be varied in order to obtain a range of $\overline{V}/\sqrt{g\ d_u}$ (Froude number) for flow over the tube. For this reason, Z will be eliminated, because the variation of **F** is of primary interest. With these limitations, Eq. 3 reduces to

$$\phi_4 \left(\frac{P}{D}, \frac{W}{D}, \lambda, \frac{d_u}{D}, \frac{Q_T}{Q}, \frac{G}{Q}, \frac{G_T}{Q}, \frac{\omega}{\overline{V}}, \frac{d_s}{D}, \frac{V}{\sqrt{g\ d_u}}\right) = 0 \ \ldots\ldots\ldots \ (4)$$

Combining $(G/Q)^{-1}$ with G_T/Q and retaining G/Q results in a parameter G_T/G that is the efficiency of trapping, E. The ratio of water removed by the tube to the total flow is represented by Q_T/Q and may be termed the extractor ratio R. The Froude number relates inertia to gravity forces and should be of prime importance in a problem of this nature. The parameter G/Q is the concentration of sediment and will be termed C. The length of tube L is needed rather than channel width so that W will be replaced by L. Eq. 4 then becomes

$$\phi_5 \left(\frac{P}{D}, \frac{L}{D}, \lambda, \frac{d}{D}, R, C, E, \frac{\omega}{\overline{V}}, \frac{d_s}{D}, \mathbf{F}\right) = 0 \ \ldots\ldots\ldots\ldots (5)$$

and presents all known variables involved in the problem.

Flow Analysis.—Because efficiency of trapping E is probably dependent on extractor ratio R, but R is independent of E, the problem should be separated into a flow analysis and sediment removal analysis. Assuming that the tube will remove the same amount of water whether clear or sediment laden and

using R as the dependent variable, the sediment factors may be omitted to yield

$$R = \phi_6\left(\frac{P}{D}, \frac{L}{D}, \lambda, \frac{d}{D}, \mathbf{F}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

For a particular series of tests, three of the independent parameters in Eq. 6 can be held constant while varying the other two. In this case, P/D (relative downstream lip elevation), L/D (relative tube length), and λ (tube shape) can be held constant for one test series and then changed and again held constant for another series. In this manner, the effect of all five variables can be determined.

The functional relationship implied in Eq. 6 can be determined analytically. The amount of flow that will be removed by the tube may be governed to some extent by width and length of slot as well as cross-sectional area of the tube. If a circular orifice is assumed then the discharge will be given by

$$Q_T = c\ A_T \sqrt{2\ g\ H} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

in which A_T is the cross-sectional area and H is the effective head on the tube, that is

$$H = d + \frac{B}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

in which d is the depth of flow in the channel at the tube, and B is depth of tube. The term c would be a modified coefficient of discharge due to tube geometry and approach velocity.

The condition of continuity in the channel over the tube section is

$$Q = A\ \overline{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

in which Q is channel discharge and A the area of flow, that is (W d). Dividing Eq. 7 by Eq. 9 results in

$$R = \frac{Q_T}{Q} = \frac{c\ A_T \sqrt{2\ g(d + B/2)}}{A\ \overline{V}} \quad \ldots\ldots\ldots\ldots (10)$$

or

$$R = \frac{c\ A_T \sqrt{2}\ \sqrt{1 + B/2\ d}}{A\ \overline{V}/\sqrt{g\ d}} \quad \ldots\ldots\ldots\ldots (11)$$

Multiplying and dividing by width of opening D, and substituting A = W d results in

$$R = \frac{c\ \left(A_T/D\right)\ \sqrt{2}\ \sqrt{1 + B/2\ d}}{W\ (d/D)\ (\mathbf{F})} \quad \ldots\ldots\ldots\ldots (12)$$

Because W = L sin θ

$$R = \frac{c\ \sqrt{2}\ \sqrt{1 + B/2\ d}}{\left(D\ L\ \sin\theta/A_T\right)\ (d/D)\ (\mathbf{F})} \quad \ldots\ldots\ldots\ldots (13)$$

For a particular design

$$R = \frac{c' \sqrt{1 + B/2\,d}}{(d/D)\ (\mathbf{F})} \quad \text{. . . . . (14)}$$

in which

$$c' = \frac{c\sqrt{2}}{\left(D\ L\ \sin\theta/A_T\right)} \quad \text{. . . . . (15)}$$

For the analysis of flow, Eq. 14 can be used together with Eq. 6. It should be emphasized that these relationships apply only when the tube is discharging freely. When the outflow is controlled, other variables are introduced into the basic relationships.

Sediment Removal Analyses.—The parameters that determine the operation of the device in the removal of sediments are given in Eq. 5. Because E is now the dependent variable,

$$E = \phi_7 \left(\frac{P}{D}, \frac{L}{D}, \lambda, \frac{d}{D}, R, C, \frac{\omega}{\overline{V}}, \frac{d_s}{D}, \mathbf{F}\right) \quad \text{. . . . . (16)}$$

Of major importance is the effect of particle size on the efficiency of trapping. Because the parameter d_s/D is more easily obtained than $\omega/\overline{V}$ in describing the sediment, it will be retained. The sediment concentration C is probably important only for large concentrations since it is conceivable that with large amounts of bed load, the tube would become overloaded. If the extractor ratio R approaches the upper limit of 100%, then the efficiency must also approach the same limit. For this reason, the efficiency must be partially dependent on the amount of water removed. Previous investigators (1), (3), (10), (11) have shown that the Froude number is particularly important. Koonsman and Albertson (4) found that the efficiency of trapping decreased as the ratio of depth to slot opening (d/D) increased.

For a particular tube design, the parameters describing the tube geometry may be held constant. For this condition, Eq. 16 reduces to

$$E = \phi_8 \left(\frac{d}{D}, R, C, \frac{d_s}{D}, \mathbf{F}\right) \quad \text{. . . . . (17)}$$

The Froude number and the resultant depth will be varied. The sediment load will be divided into different size ranges so that the relationship of size to efficiency will be determined.

Stable Channel Design and Sediment Transport.—Although the vortex tube sand trap may be installed in both lined and unlined canals, the unlined section is of primary importance. Here the purpose of the ejector is to assist in stabilization of a channel that is otherwise unstable. A stable channel is defined as an unlined earth canal for carrying water, the banks and bed of which are not scoured by moving water, and in which deposits of sediment do not occur. Many investigators have developed design criteria for stable channels. Notable among the recent studies have been those of Blench (2), Lane (5), and Simons (12). Relationships have been developed using both regime and tractive force theories for determining width, depth, and slope of a stable channel in erodable material.

The purpose of sand ejectors is to remove a portion of the sediment that is moving as bed load rather than suspended load. Bed load is defined as that portion of the sediment load, usually coarse material, that is moving on or near the channel bed. There is no distinct dividing line separating suspended and bed load. Size of material that may be transported either as bed or suspended load covers a fairly broad range and depends on many factors. Any given channel is capable of transporting a certain quantity of sediment depending on related factors such as shape of channel, size of sediment, slope of the energy gradient, and amount of wash load. The effect of reducing the sediment load of an otherwise stable channel is to initiate scour and hence non-equilibrium. Conversely, deposition will occur if the sediment load is increased above the stability level. The balance between stability of a channel and charge has been given by Lane (6). The relationship he presents is

$$G\ d_s \sim Q\ s_e \qquad (18)$$

in which G is the quantity of sediment being discharged, d_s the mean particle diameter, Q the water discharge, and s_e the slope of the energy gradient. This expression shows that, if a stream in equilibrium has its sediment load decreased equilibrium can be restored by decreasing Q and s_e or a combination of the two.

Simons (12) found that stable earth canals through soils in the sandsilt range generally carried less than 500 ppm of total load exclusive of wash load. In effect, this would mean that canals in this material, carrying heavier loads, could be stabilized if the load were reduced below the 500 ppm level.

From this information, it would seem that the primary purpose of a sand ejector is not to remove all the sediment but rather to reduce the load to a level that can be carried under stable conditions. The difference between the load being carried in the unstable condition and that necessary to establish a stable channel is the amount that the extractor would be required to remove.

The forms of bed roughness in an alluvial channel are dependent on the bed material, sediment in transport, and characteristics of the flow (13). Laboratory studies by Simons and Richardson for the United States Geological Survey (USGS), at Fort Collins, Colo., and a field study by Simons (12) have shown that the following approximate relationship exists for channels in sandy material having a mean diameter of 0.45 mm.

Flow Regime and Form of Bed Roughness	Total Sediment Load in Percent
Tranquil Flow Regime ($F < 1$)	
(1) Plane bed without movement of the bed material	----
(2) Ripples	0.0 - 0.0075
(3) Dunes	0.0075 - 0.1
(4) Transition from dunes to rapid flow	0.1 - 0.3
(5) Plane bed with movement of bed material	0.3 - 0.4

Rapid Flow Regime ($\mathbf{F} > 1$)

(6) Standing water waves and sand waves	0.4 - 0.6
(7) Antidunes	> 0.6

The forms of bed roughness in the foregoing table are arranged in order of increasing Froude numbers.

Of importance in the design of the vortex tube sand trap is the manner in which the bed load will be traveling. In the case of dune bed roughness, bed material is traveling in waves or slugs, and the suspended load is relatively large. The amount moving past a certain point will vary with time. In this case, it is foreseeable that at the time a dune reaches the tube, the tube would become completely covered with sediment and would be rendered inoperative. This phenomenon has been observed on both field structures and laboratory studies. With the plane bed form of roughness, movement of bed load is reasonably continuous and at fairly constant rate.

With these factors in mind, the section containing the tube should be designed so that flow conditions in the section are in the regime in which a plane bed will exist. According to Simons and Richardson, this form of roughness exists at a Froude number range of 0.4 - 0.5 for material with a mean diameter of 0.28 mm and 0.6 - 0.7 for a mean diameter of 0.45 mm. From these ranges, it is logical to assume that as size of material is increased, the Froude number must also be increased in order to maintain plane bed condition.

EQUIPMENT AND PROCEDURE

The flume used for the study was available in the Hydraulics Laboratory at Colorado State University, Fort Collins, Colorado. This flume is 160 ft long, 8 ft wide, and is adjustable for slope. A system of large centrifugal pumps recirculates the water and sediment. Maximum flows near 20 cfs are possible. Sand of desired gradation can be placed to depths of 6 in. to 8 in. throughout the length of the flume. The field situation of sediment transport is simulated because of the recirculation feature and size of flume.

For tests of the vortex tube, a section containing the tube was placed in the flume near the downstream end [see Figs. 2, 3(a), and 3(b)]. This section was constructed so that tubes of different shapes and sizes could be inserted. The sediment and water discharge from the tube was conveyed by pipe into a head box and thence through a Parshall measuring flume [Fig. 3(c)]. Periodically, this flow was diverted into a weighing tank for determining the amount and size of sediment being removed. The sediment discharge past the tube was determined using a sampler that traveled across the overfall from the flume [Fig. 3(d)]. Several traverses were made to obtain a single representative sample. Duplicate samples were usually taken from both the tube and traversing samplers.

The total water discharge through the flume was determined using calibrated orifices in the pump discharge lines. Depths of flow were measured using a point gage mounted on a movable carriage. The water surface profile was determined beginning at a point several feet upstream from the vortex tube section and extending downstream from the section. The depths of flow were adjusted using the movable tailgate [Fig. 3(b)].

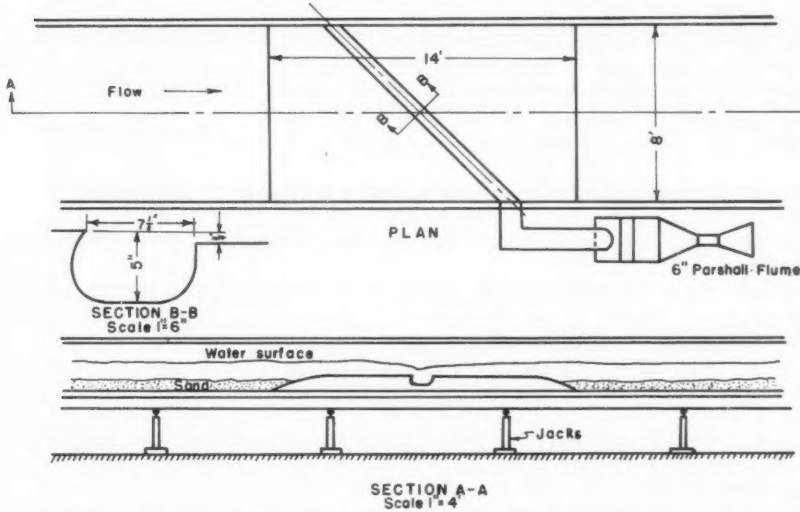
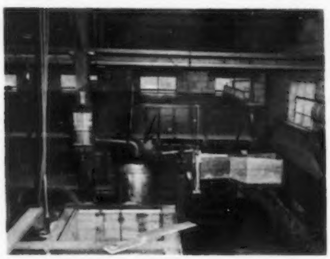


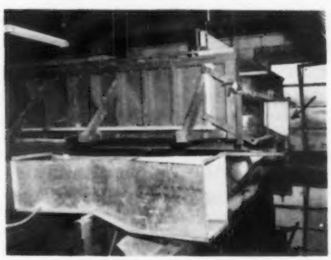
FIG. 2.—LAYOUT OF VORTEX TUBE SAND TRAP FOR LABORATORY STUDY

(a) Vortex tube in place showing sand bed upstream.

(b) Vortex tube showing end gate for controlling depths of flow.



(c) Devices used for measuring and sampling flow from tube.



(d) Traversing end sampler for determining sediment passing tube.

FIG. 3.—DETAILS OF EQUIPMENT USED FOR LABORATORY STUDY OF VORTEX TUBE

The bed material used in these tests was a granitic sand having a median size of 0.53 mm. Of the entire sand fraction, 22%, by weight, was finer than 0.30 mm, and 25% was larger than 0.83 mm. For the purpose of determining the relationship of size of material to efficiency of trapping the samples were broken into size ranges consisting of fraction $>$ 0.83 mm, fraction 0.59-0.83 mm, fraction 0.30-0.59 mm, and fraction $<$ 0.30 mm.

Basically, the procedure followed in conducting the tests was as follows:

(1) A flow was established and allowed to stabilize for a period of 2 hr. to 4 hr.

(2) After this period, the total water discharge and that from the tube was determined.

(3) Water surface profiles and depths were measured using the traveling point gage.

(4) Samples for sediment analyses were taken.

(5) The depth of flow for the particular discharge was then changed, and the procedure repeated after the 2 hr to 4 hr stabilization period.

A range of Froude numbers of from 0.3 to 1.4 was covered for a constant discharge. On completion of this range, the discharge was changed and the procedure repeated.

A limited number of additional tests were also made utilizing tubes installed in a flume that was 4 ft wide. In this case, sediment was not used, since the purpose was to study only the characteristics of flow from the tube. With the 4-ft width, it was possible to observe the action of tubes that were one-half the length of those in the 8-ft flume. For these tests, the amount of flow from the tubes was controlled by submerging the tube outlet. Piezometers were installed in one tube to observe the distribution of piezometric head around the periphery of the tube. Particles of the same specific gravity as sand were injected into the tube to measure the translation velocities.

Designs of the different tubes used in this study are shown in Table 1. In these tests, the design listed for series 1 is identical in shape to the one found to be superior in trapping by Rohwer (series 6). The tube listed for series 4 to 10 was modified from 0.5 ft ID steel pipe. Also shown in Table 1 are designs used by Rohwer (11) and the one used by Koonsman (3) because data from these tests are also presented in this report.

Two field installations of vortex tubes designed by Ralph L. Parshall are shown in Fig. 4. These two structures have each been termed highly successful although quantitative measurements have not been made. Because of large quantities of bed load involved, two parallel tubes were used in the structure shown in Fig. 4(a). The sides of the structure were contracted and the bottom raised to increase the velocity across the tubes. Shown in Fig. 4(a) is the outlet works to convey the removed flow back to the river. Two tubes were also used in the installation shown in Fig. 4(b) to reduce the length of a single tube. Each tube discharges into a catchment basin in the center, which, in turn, discharges through a buried pipe under the structure into the return channel.

ANALYSIS OF DATA

One objective of this study was to correlate the results of past investigations with the current experiments. These studies were all essentially laboratory studies since no field evaluations have been made. However, except for

TABLE 1.—TEST DESIGNS OF VORTEX TUBES

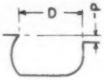
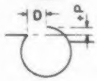
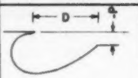
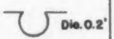
Series No.	Tube Shape	Area (A) ft^2	Length (L) ft.	Depth (B) ft.	Opening (D) ft.	Downstream Lip Position (P) ft.
Robinson 1		0.244	11.31	0.417	0.625	-0.062
2		.261	11.31	.417	.561	+.005
3		.280	11.31	.417	.520	+.064
4		.170	11.31	.440	.375	-.062
5		.184	11.31	.440	.308	+.020
6		.197	11.31	.440	.287	+.091
7		.170	11.31	.440	.375	-.062
8		.182	11.31	.440	.325	+.009
9		.194	11.31	.440	.232	+.080
10		.196	11.31	.440	.204	+.086
11	Same as 1	.244	5.48	.417	.625	-.062
12	Same as 4 & 7	.170	5.48	.440	.375	-.062

TABLE 1. —*CONTINUED*

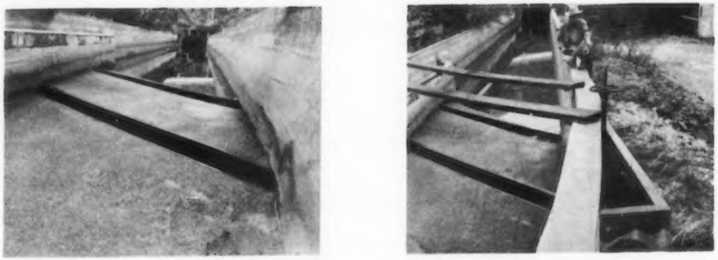
Series No.	Tube Shape	Area (A) ft^2	Length (L) ft.	Depth (B) ft.	Opening (D) ft.	Downstream Lip Position (P) ft.
Rohwer 1		.234	11.31	.417	.625	-.125
2		.238	11.31	.417	.625	.000
3		.256	11.31	.417	.625	-.062
4		.256	11.31	.417	.583	-.083
5		.184	11.31	.417	.583	-.083
6		.262	11.31	.416	.625	-.062
7		.138	11.31	.292	.469	-.042
Koonsman		.0286	2.83	.172	.142	.000

Note - Rohwer Series 1-7 tubes tapered. Average dimensions shown except for length.

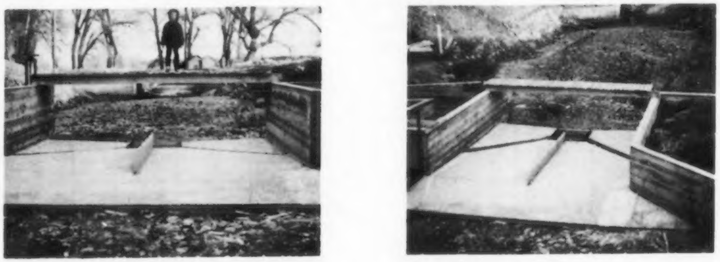
the work of Koonsman (3), the laboratory studies were made on large structures comparable to the sizes used in the field.

An understanding of the hydraulics of flow in the tube is essential in order to analyze the efficiency of trapping. For this reason, the problem has been broken down into a flow and sediment removal analysis so that these phases will be dealt with separately and then combined to show the total effect.

Flow-Analysis.—The general relationship presenting the parameters that are of importance in the hydraulic behavior of the vortex tube are given in Eq. 6. Eq. 14 was developed by assuming that the flow from the tube can be determined by the general orifice equation. This was the case for free flow from the tube. Fig. 5 illustrates the validity of this relationship. Fig. 5 shows the results of five series of tests made with tubes of two different designs. Values of c' in Eq. 14 are shown for each series. Note that extractor ratio R is inversely proportional to the parameter d/D and the Froude number. For a constant depth, the percentage of flow removed would be increased if the opening D is increased or the velocity decreased.



(a) Installation in the Handy Canal near Loveland Colorado using two parallel tubes.



(b) Structure in the Ish Canal near Berthoud, Colorado using two tubes discharging into a central bay.

FIG. 4.—FIELD INSTALLATIONS OF VORTEX TUBE AND SAND TRAPS

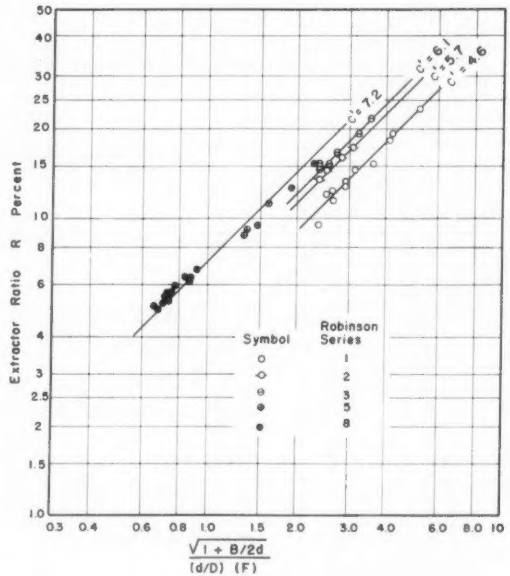


FIG. 5.—EXTRACTOR RATIO AS A FUNCTION OF d/D AND FROUDE NUMBER

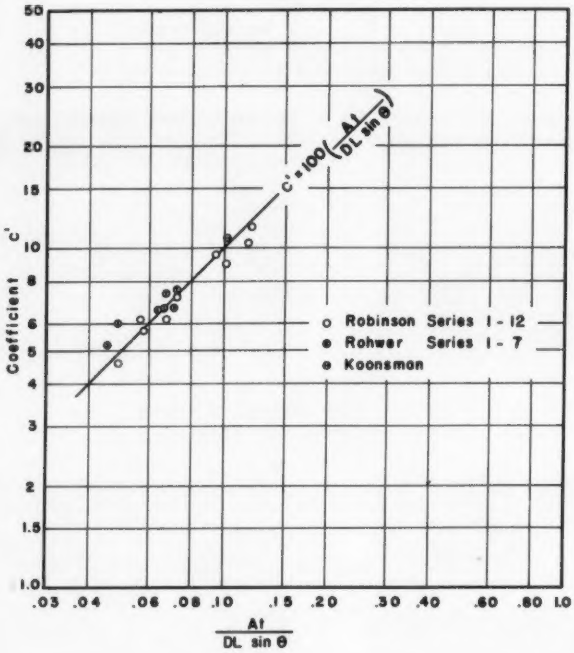


FIG. 6.—DISCHARGE COEFFICIENT AS A FUNCTION OF TUBE GEOMETRY

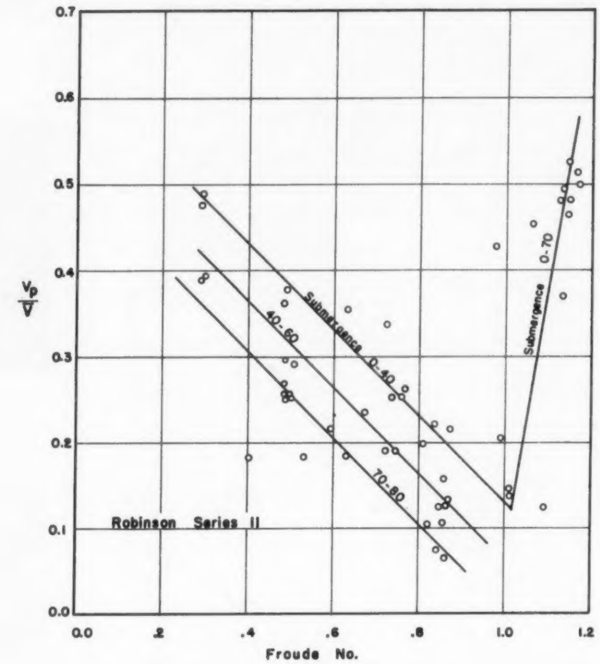


FIG. 7.—RELATIONSHIP OF PARTICLE VELOCITY AND FROUDE NUMBER

Values of c' are shown in Table 2 for all the present tests together with those from Rohwer (11) and Koonsman (3). These are values determined when expressing extractor ratio R in percent. Also given are the parameters describing the tube geometry. In the case of the tapered tubes (Rohwer 1 through 7), the area of tube was that at the outlet end. The relationship of this

TABLE 2.—SUMMARY OF FLOW ANALYSES OF VORTEX TUBES

Series	$\frac{P}{D}$	$\frac{L}{D}$	$\frac{A_T}{D\ L\ \sin\theta}$	c'
Robinson				
1	-0.100	18.1	0.0487	4.6
2	+ .009	20.2	.0580	5.7
3	+ .123	21.8	.0672	6.1
4 and 7	- .166	30.2	.0565	6.2
5 and 8	+ .044	35.8	.0722	7.2
6 and 9	+ .331	43.6	.095	9.6
10	+ .421	55.5	.120	11.5
11	- .100	8.8	.101	9.0
12	- .166	14.6	.117	10.4
Rohwer[a]				
1	- .200	18.1	.0650	6.7
2	.000	18.1	.0652	6.7
3	- .100	18.1	.0706	6.7
4	- .142	19.4	.0670	7.4
5	- .142	19.4	.0450	5.2
6	- .100	18.1	.0723	7.6
7	- .089	24.1	.0485	6.0
Koonsman	.000	19.9	.101	10.7

[a]Rohwer series 1-7 used tapered tubes.

parameter to the coefficient c' is shown in Fig. 6 with the equation being,

$$c' = 100\left(\frac{A_T}{D\ L\ \sin\theta}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

It should be emphasized that the data shown in Fig. 6 includes that from a variety of tube shapes, lengths, and areas so that Eq. 19 is the general relationship. With Eq. 19, it is then possible to determine the coefficient c' in Eq. 14 for a tube design. For a given depth of flow and corresponding velocity, the percent of flow that will be removed can be determined with a probable accuracy of $\pm$ 10%.

One other parameter in the analysis of the free flow discharge from the tube was not considered in the foregoing discussion. This is the relative elevation of the downstream lip of the tube, that is, P/D. Because of the interrelationship of P with D and A_T in the present experiments, it was not possible to separate the effects of this variable. In general, it was noted that as the downstream lip was raised, the percent of flow removed was increased slightly. The deviation of points in Fig. 6 was not entirely due to the variation of the parameter P/D.

In the previous work by Rohwer (10) (11), tests were made to determine the relative operation of the tube when the flow from the tube was controlled. This control was accomplished by adjusting the water level in a chamber into which the tube discharged. This same scheme was used in the tests on the Robinson series 11 tests. The percent of tube submergence was determined as the ratio of depths in the channel to those in the control chamber taken from a base that was the floor of the section containing the tube. With this base, tube submergence was zero until the water level in the chamber was above the top of the tube outlet.

The tests on the effect of controlling the tube discharge by end submergence were inconclusive. Generally, the relationship for tubes operating under submergences up to 40% was the same as for free flow. For this condition, the value of the coefficient c' was 9.0. As the submergence was increased beyond 40%, the extractor ratio decreased. At 90% submergence, the percentage of flow removed was less than one-half that for the 0% through 40% condition.

The tests by Rohwer (10), (11) indicated that the flow from the tube could be reduced in the manner described, and yet high efficiencies of trapping could be maintained. In essence, this would mean that the translation velocity within the tube would be maintained under these conditions. Results of observations made during the Robinson series 11 tests are shown in Fig. 7. The relationship of the parameter $V_p/\overline{V}$ to the Froude number, with the percent of submergence as the third variable is shown. V_p is the translation velocity that was the velocity of a particle along the tube and $\overline{V}$, the mean velocity of the flow over the tube.

Although the relationships in Fig. 7 are not well defined due to scatter of data, definite trends are noted. As the Froude number increases to a value of 1 the velocity ratio decreases. Beyond a Froude number of 1 this ratio increases sharply. For a given Froude number below 1, the ratio of $V_p/\overline{V}$ decreases as the percentage of tube submergence increases, indicating that the translation velocity has decreased because the mean velocity remains constant. Examination of data from Rohwer (10) indicated almost identical trends, with the lowest value of $V_p/\overline{V}$ being near a Froude number of 1.

Water surface profiles and piezometric head distribution in the vicinity of the vortex tube is given in Fig. 8. This was for a constant discharge and tube design used in Robinson series 11 tests. The Froude numbers indicated on each profile were determined using the depth 1 ft upstream from the tube. In each case, the piezometer in the L-4 location gave a pressure greater than the water depth. This was probably due to impact or change of momentum of the jet being greater at this point. At the L-3 location, that is in the bottom of the tube, piezometric head was always lower than the water depth, being the lowest at the higher Froude number and increasing as the Froude number decreased. Of particular interest are the determinations made at the L-1 location directly under the upstream lip of the tube. Contrary to a belief that negative pressures exist at this point, the piezometric head was always greater than water depth except at the highest Froude number. The magnitude of the variation of piezometric head from water depth is an indication of the vorticity within the tube. This variation is essentially constant for the higher Froude numbers down to a value of 0.85 after which it decreases rapidly.

Sediment Removal Analysis.—Using dimensional analysis the parameters that should affect the efficiency of trapping were arranged in dimensionless form as given in Eq. 16. For a particular tube design, those terms describing the shape are held constant. For this condition, Eq. 16 reduces to Eq. 17, that

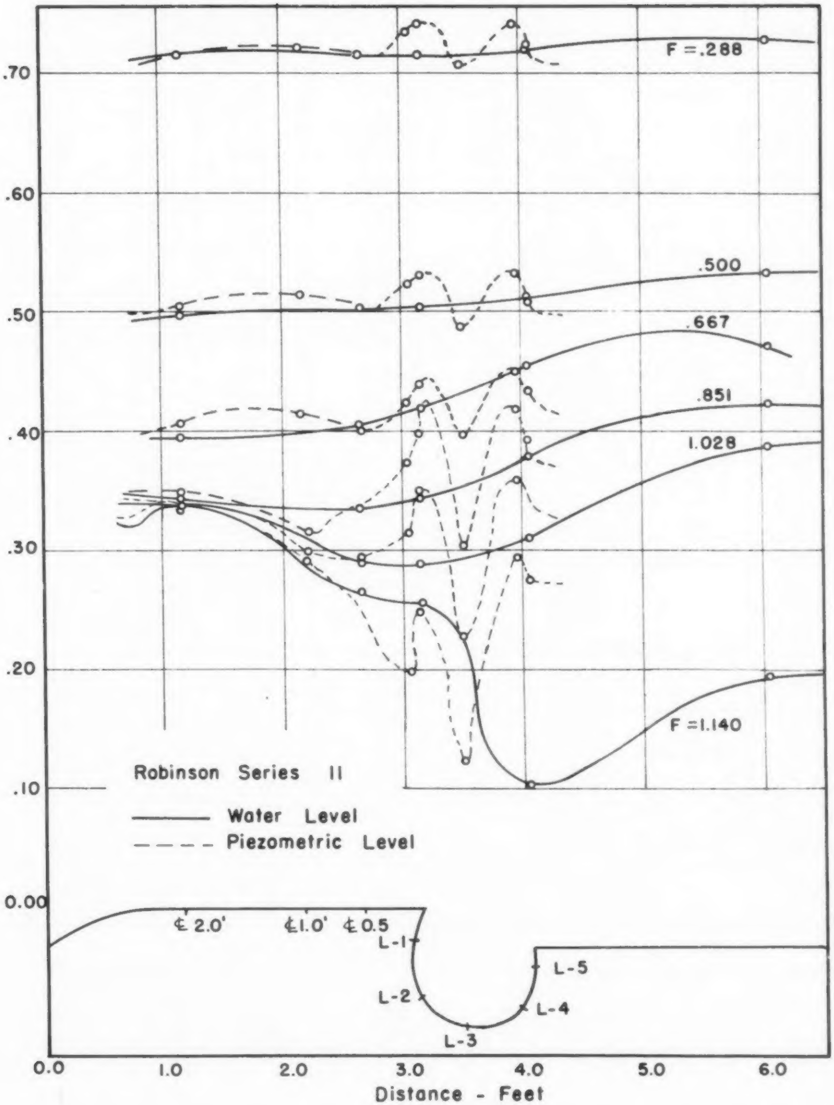


FIG. 8.—RELATIONSHIP OF FLOW DEPTH TO PIEZOMETRIC LEVEL

TABLE 3.—SUMMARY OF VORTEX TUBE EFFICIENCY—ROBINSON

Series No.	d/D range	F	Trapping efficiency in percent 0.83 mm	0.59 - 0.83 mm	0.30 - 0.59 mm	0.30	Total Sample
1	0.39-0.96	1.2	79.0	72.0	70.0	24.0	36.0
		1.0	85.5	77.5	75.0	26.5	41.0
		0.8	90.5	81.5	78.5	28.0	45.0
		0.6	93.5	84.0	81.5	30.0	49.5
3	.72-1.05	1.2	92.5	83.5	74.0	29.5	47.0
		1.0	92.0	84.0	75.0	31.0	49.0
		0.8	91.0	84.5	75.5	32.5	50.5
		0.6	91.0	84.5	76.0	34.0	52.0
4	.72-1.15	1.2	72.0	69.5	62.0	27.0	49.5
		1.0	62.0	59.5	58.0	28.5	42.0
		0.8	67.0	61.5	60.0	25.0	41.0
		0.6	81.5	70.0	66.0	26.0	45.0
5	1.00-1.56	1.2	89.0	78.5	65.0	25.0	47.5
		1.0	86.0	77.5	63.5	25.0	47.0
		0.8	84.5	77.5	61.5	24.0	45.5
		0.6	85.5	79.0	59.0	43.0	23.5
6	1.39-1.83	---	----	----	----	----	----
		1.0	88.5	79.0	71.0	39.5	61.5
		0.8	80.0	65.0	51.0	32.0	49.0
		0.6	78.0	61.5	40.5	24.5	37.0
7	1.23-2.50	1.2	50.0	42.5	32.5	17.5	30.5
		1.0	50.0	45.0	35.0	18.5	32.5
		0.8	61.0	54.0	45.0	23.5	38.5
		0.6	73.5	69.0	58.0	29.0	39.5
8	1.53-3.15	---	----	----	----	----	----
		1.0	73.0	67.0	58.5	34.0	54.0
		0.8	67.0	59.0	52.0	31.0	48.0
		0.6	58.0	47.5	41.0	24.0	37.5
9	2.56-4.46	---	----	----	----	----	----
		1.0	91.0	83.0	71.0	34.0	67.0
		0.8	80.0	73.0	62.0	33.0	55.5
		0.6	63.0	52.0	46.5	26.0	37.5
10	2.91-4.76	---	----	----	----	----	----
		1.0	70.5	62.5	53.0	27.5	48.0
		0.8	60.5	52.0	45.0	23.0	39.5
		0.6	42.5	32.0	26.0	18.0	23.0
				Average for all tubes			
		1.0	77.6	70.6	62.2	29.4	49.1
		0.8	75.7	67.6	58.9	28.0	45.8
		0.6	74.0	64.4	54.9	28.3	38.3

will be the primary relationship examined. The parameter describing the sediment size d_s/D will be reduced to only d_s in order to make the analysis more understandable.

The efficiency of trapping as a function of Froude number and sand size are shown in Figs. 9, 10, and 11. These are representative tests on two different shapes of tubes. The results from all tests are given in Table 3. The effect of sand size on trapping efficiency is noteworthy. In each case, the

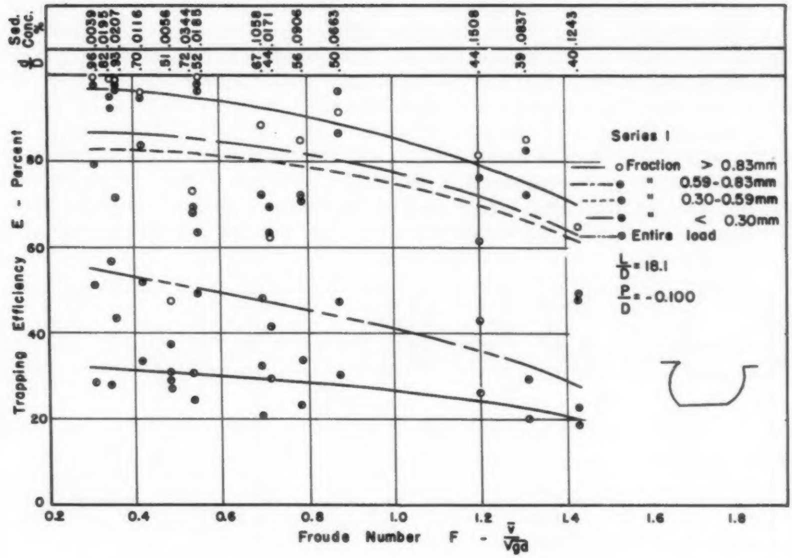


FIG. 9.—TRAPPING EFFICIENCY AS A FUNCTION OF FROUDE NUMBER AND SAND SIZE

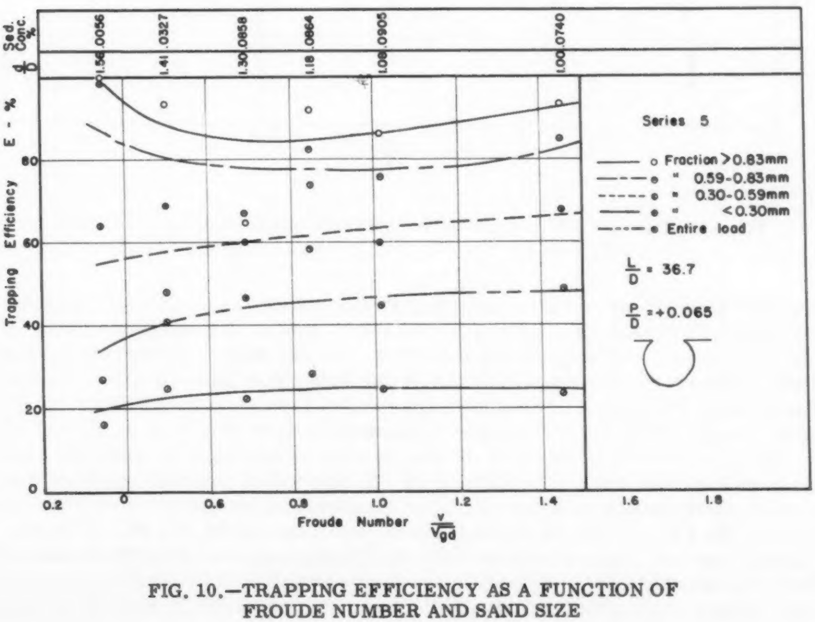


FIG. 10.—TRAPPING EFFICIENCY AS A FUNCTION OF FROUDE NUMBER AND SAND SIZE

highest efficiency was obtained for coarser material, that is, greater than 0.83 mm. As the size was decreased to 0.30 mm, the efficiencies correspondingly dropped. For that material smaller than 0.30 mm, the efficiency of trapping was very low. If the entire sand sample was considered the efficiency was low but higher than that for the finest fraction of material.

The amount of total load for each run is also given in Figs. 9, 10, and 11. These concentrations varied from 0.004 to 0.28 in percent by weight (40 ppm to 2800 ppm). No effect of concentration on efficiency was noted, probably because the maximum concentration was relatively low. In fact, those tests shown in Fig. 11 indicate an increase in efficiency with an increasing sediment load. It is conceivable that for very high concentrations the tube would

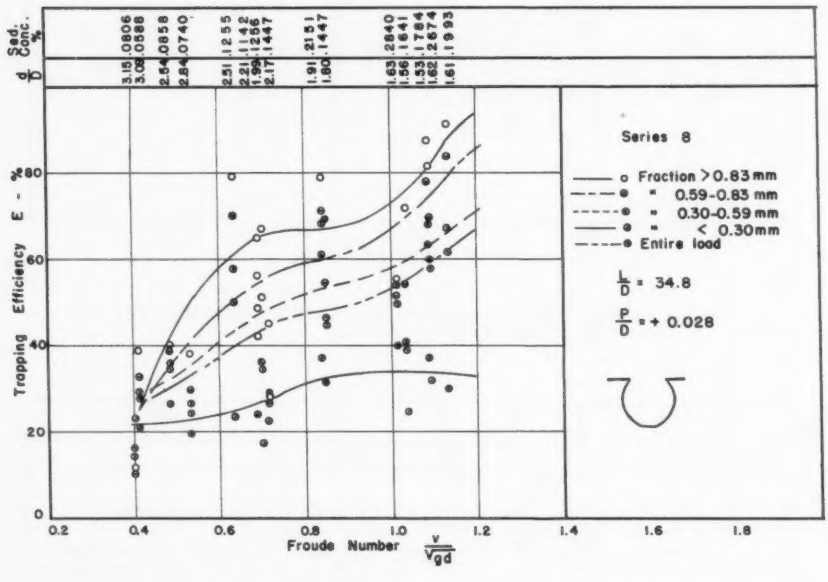


FIG. 11.—TRAPPING EFFICIENCY AS A FUNCTION OF FROUDE NUMBER AND SAND SIZE

become plugged or overloaded so that the efficiency would be reduced. Koonsman (3) found that this was the case with the maximum concentration at which the tube became overloaded varying with the depth of flow. When the depth of flow was equal to diameter of the tube, this critical concentration was 0.45% (4500 ppm). When the depth was three times the diameter of the tube, the efficiency began to drop at a concentration of 0.20%.

The parameter d/D, or depth divided by width of opening, is shown for each set of data plotted in Figs. 9, 10, and 11. In Fig. 9 this value varies from 0.39 to 0.96. Test results on tubes of almost identical shapes are given in Figs. 10 and 11. In Fig. 10, the magnitude of d/D varied from 1.00 to 1.56. The efficiencies are relatively constant over the entire range of Froude numbers. However, in Fig. 11 the efficiencies are very low at the low Froude numbers and higher values of d/D. This plot shows a range of d/D from 1.53 to 3.15.

From these data it seems that the efficiency generally decreases as depth is increased for a given tube design. A similar conclusion was reached by Koonsman (3). In general, it can be said that the Froude number seemed to have very little effect on the trapping efficiencies when the value of d/D was below approximately 1.5.

Table 3 gives the average efficiencies for different sand fractions as well as for the total sample for a range of Froude numbers. For the series 1 and 3 tests, efficiencies of trapping were high and relatively constant over the entire range of Froude numbers. The physical design of tubes used in these tests is given in Table 1. The range of d/D values for these tests was 0.39 to 1.05. Series 4 and 7 utilized tubes of the same shape, but the values of d/D were greater in series 7, that evidently resulted in lower efficiencies. Series 10, in which d/D ratios were largest, gave the lowest overall efficiencies. In general, the tubes tested using the lowest d/D values gave almost constant efficiencies for a given gradation regardless of Froude number. For all series, the efficiency of trapping material smaller than 0.30 mm was very low.

TABLE 4.—SUMMARY OF VORTEX TUBE EFFICIENCY—KOONSMAN

$\frac{d}{D}$	F	Trapping Efficiency Total Sample[a] percent
1.41	1.2	80
	1.0	88
	0.8	60
	0.6	49
2.82	1.2	64
	1.0	70
	0.8	62
	0.6	--
4.23	1.2	--
	1.0	61
	0.8	57
	0.6	--

[a]Median diameter 0.65 mm. - Size range 0.3-2.0 mm.

A summary of tests by Koonsman (3) is given in Table 4. The highest efficiency in trapping was noted at a Froude number equal to 1 (critical velocity) and decreased when this parameter was either greater or less than 1. Higher efficiencies were noted at lower d/D ratios, that is, flow depths, because the opening width D remained constant. The indicated efficiencies are for the entire sample used in the test, that had a median diameter of 0.65 mm and a size range of from 0.3 to 2.0 mm.

The results of tests by Rohwer (11) are given in Table 5. The tube shapes and dimensions are given in Table 1. For series 1-5, the efficiencies generally decreased as the Froude number decreased with no conspicuous difference between the different tube shapes. The tube used in series 6 tests was identical in shape to that used in Robinson series 1 with the exception that it was tapered rather than straight. For each sand size this tube gave almost con-

stant trapping efficiencies regardless of magnitude of Froude number. These efficiencies were also higher on the average than those for the other tubes. Again efficiency decreased as sand size decreased. Values of d/D ranged from 0.62 to 4.00 for these tests. For those tests in series 7, the tube had the

TABLE 5.—SUMMARY OF VORTEX TUBE EFFICIENCY—ROHWER

Series	$\frac{d}{D}$ range	F	Trapping efficiency		
			River sand[a]	Fine sand[b]	Blow sand[c]
1	1.04-3.71	1.4	75		
		1.2	72		
		1.0	70		
		0.8	67		
		0.6	65		
2	1.10-2.98	1.4	--		
		1.2	93		
		1.0	81		
		0.8	69		
		0.6	57		
3	0.66-3.09	1.4	94		
		1.2	82		
		1.0	70		
		0.8	59		
		0.6	47		
4	0.65-2.25	1.4	92		
		1.2	80		
		1.0	67		
		0.8	54		
		0.6	41		
5	0.69-1.34	1.4	75		
		1.2	73		
		1.0	69		
		0.8	62		
		0.6	53		
6	0.62-4.00	1.4	85	73	41
		1.2	87	74	43
		1.0	88	76	45
		0.8	89	77	46
		0.6	90	78	48
7	0.85-4.40	1.4	79	57	33
		1.2	78	59	34
		1.0	77	61	35
		0.8	76	64	36
		0.6	76	66	38

[a]Median diameter 1.75 mm - 1.2% < 0.3 mm and 30% > 2.8 mm (by weight).
[b]Size unknown but smaller than river sand and larger than blow sand.
[c]Median diameter 0.38 mm - 26% < 0.3 mm and 0.0% > 0.59 mm (by weight).

same relative shape as in series 6 but was smaller in area. The efficiencies were lower than those in series 6 but remained constant throughout the Froude number range.

The effect of depth of flow divided by the width of opening (d/D) on the efficiency of trapping is shown in Figs. 12 through 17 for the Robinson tests.

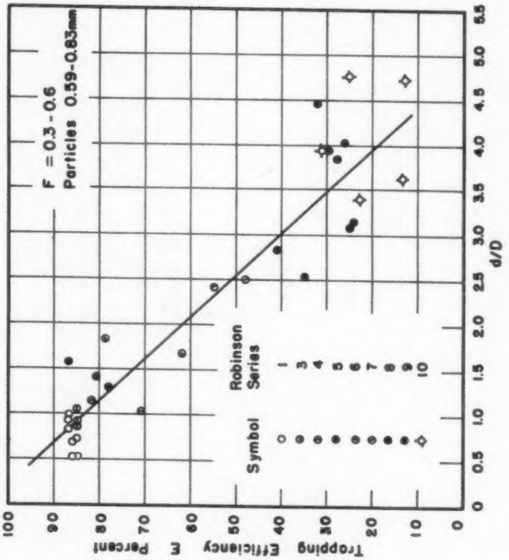


FIG. 13.—TRAPPING EFFICIENCY AS A FUNCTION OF d/D FOR PARTICLE SIZE RANGE OF 0.59-0.83 mm AND FROUDE NUMBER RANGE 0.3-0.6

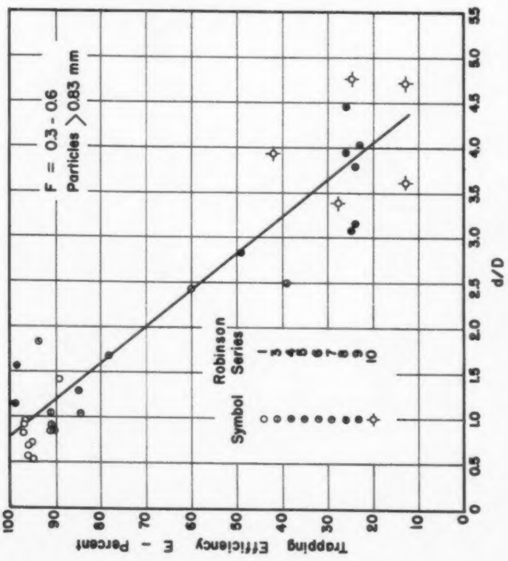


FIG. 12.—TRAPPING EFFICIENCY AS A FUNCTION OF d/D FOR PARTICLE SIZES GREATER THAN 0.83 mm AND FROUDE NUMBERS IN THE RANGE OF 0.3 - 0.6

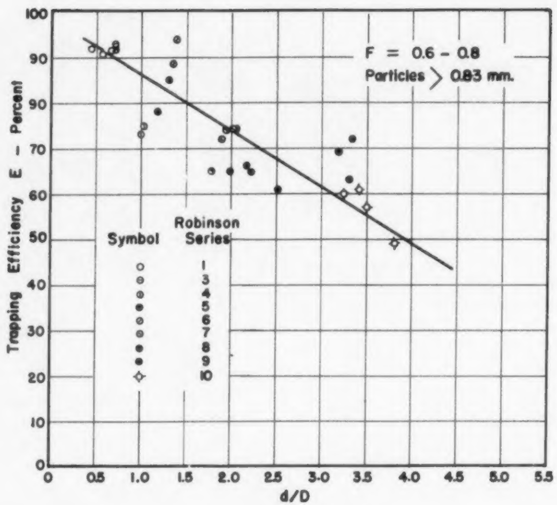


FIG. 14.—TRAPPING EFFICIENCY AS A FUNCTION OF d/D FOR PARTICLE SIZES GREATER THAN 0.83 mm AND FROUDE NUMBERS IN THE RANGE OF 0.6–0.8

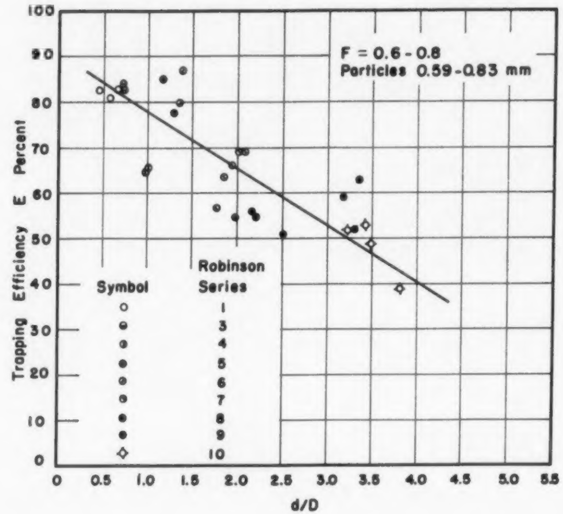


FIG. 15.—TRAPPING EFFICIENCY AS A FUNCTION OF d/D FOR PARTICLE SIZE RANGE OF 0.59–0.83 mm AND FROUDE NUMBER RANGE 0.6 - 0.8

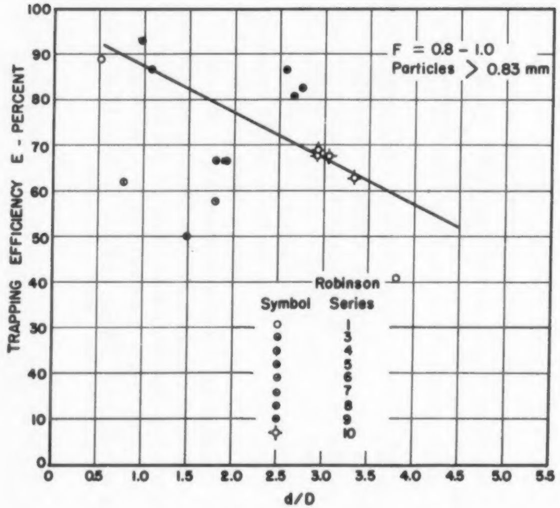


FIG. 16.—TRAPPING EFFICIENCY AS A FUNCTION OF d/D FOR PARTICLE SIZES GREATER THAN 0.83 mm AND FROUDE NUMBERS IN THE RANGE OF 0.8 - 1.0

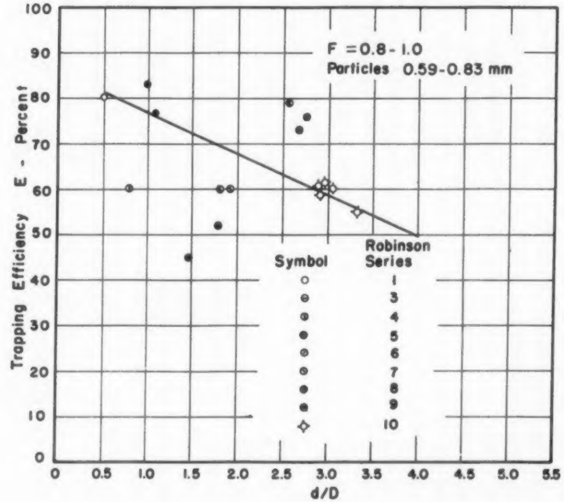


FIG. 17.—TRAPPING EFFICIENCY AS A FUNCTION OF d/D FOR PARTICLE SIZE RANGE OF 0.59-0.83 mm AND FROUDE NUMBER RANGE OF 0.8 - 1.0

Two sizes of material have been considered, that greater than 0.83 mm. and the fraction in the range of 0.59 to 0.83 mm. The range of Froude numbers has been divided into three categories: from 0.3 to 0.6, 0.6 to 0.8, and 0.8 to 1.0. For the range of Froude numbers of 0.3 to 0.6, and for both sand fractions (Figs. 12 and 13), the efficiency drops sharply as the value of d/D increases. It should be pointed out that the data from all tests and corresponding tube designs for the present experiment are included on these plots.

In Figs. 14 and 15 are shown the relationships in the range of Froude numbers of 0.6 to 0.8. Here the effect of the relative depth d/D is not as pronounced as in the F range of 0.3 to 0.6. The data in Figs. 16 and 17, that are for higher Froude numbers (0.8 to 1.0), do not show a definite trend. Generally, it can be observed that efficiency also decreases as relative depth increases but to a smaller magnitude than for the other cases. For the largest material, the highest trapping efficiencies were those for the Froude number range of 0.3 to 0.6 and d/D values less than 2.

The effect of variation in the parameter L/D, that is the length of tube divided by the slot opening, on the trapping efficiency was noted. In general, the trapping efficiency decreased as the length or L/D ratio was increased. From field observations, it has been noted that there is a limiting length for a given size tube for optimum operation. From these data and the field observations, it might be said that the length over opening ratio should not exceed 20 if an efficiency of greater than 80% is to be expected for the larger materials. Several successful field installations have L/D ratios in the range of 11 through 15. In general, the lengths have not exceeded 17 ft in the field structures.

As stated in the analysis, the extractor ratio, or percentage of flow removed by the tube, must be important because if all the flow was removed then the efficiency would be 100%. In Figs. 18 and 19, the efficiency as a function of extractor ratio is given for the data from the present experiment. Lines of constant values of d/D and the Froude number are also shown. These relationships were determined from interpolation of values for each point, use of Figs. 12 through 17 and from Eq. 14. In the use of Eq. 14 and the figures, it was necessary to determine average values for c' and $\sqrt{1 + B/2\,d}$. The variation in c' was in the order of 20% from the mean with $\sqrt{1 + B/2\,d}$ approximately 6%.

The results shown in Figs. 18 and 19 indicate that the efficiencies are high for all values of d/D less than 1.5 and are almost independent of extractor ratio in this range. As the value of d/D increases, higher Froude numbers must be maintained in order that efficiencies remain at a high level. At large values of d/D and low Froude numbers, the efficiency is very low. As in the previous discussion, efficiencies are lower for the smaller sizes of material.

One variable given in Eq. 16 that has not yet been considered in trapping efficiency, is relative elevation of the downstream lip of the tube given by the parameter P/D. From plots of constant Froude number and sediment size, it was determined that there was no effect depending on the location of the downstream lip other than that previously discussed in the flow analysis. This indicated that as the lip was raised the percentage of total flow was increased.

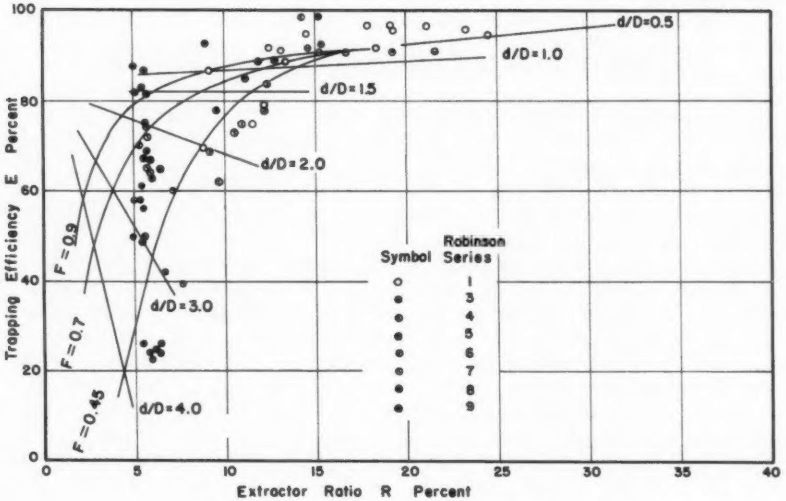


FIG. 18.—TRAPPING EFFICIENCY AS A FUNCTION OF EXTRACTOR RATIO, FROUDE NUMBER AND d/D RATIOS FOR PARTICLE SIZES > 0.83 mm

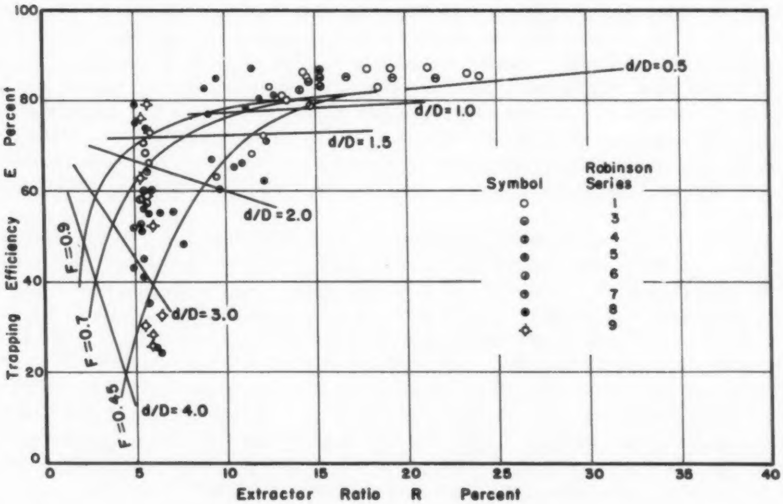


FIG. 19.—TRAPPING EFFICIENCY AS A FUNCTION OF EXTRACTOR RATIO, FROUDE NUMBER AND d/D RATIOS FOR PARTICLES SIZES IN THE RANGE OF 0.59 - 0.83 mm

Any increase in efficiency would probably be due to the increase in amount of water removed.

ANALYSIS OF RESULTS AND DESIGN RECOMMENDATIONS

In the analysis of flow from the tube, it was found that percentage of flow removed was a function of tube geometry and angle, as well as depth and velocity of flow across the section. Parameters describing the tube were the length, width of slot, and area. With the other factors that effect the sediment removal characteristics of the tube being considered, it was noted that tubes with values of c' in the range of 4.6-7.6 were most successful. For design purposes this would limit the range of the geometry parameter $A_T/D\ L \sin \theta$ from approximately 0.05-0.07 (see Fig. 6). In the section on sediment removal, it was pointed out that the parameter L/D should not exceed a value of 20 for optimum operation. Successful field structures exist with L/D values as low as 11. For practical purposes, as well as past experiences, the width of slot D should probably be in the range of 0.5 through 1.0 ft. Past studies have indicated that an angle of 45° for the tube is desirable. With the range of these factors known, it is then possible to compute the area of tube needed.

A study of the data revealed that there was no discernible difference when having the two lips of the tube level, or the downstream lip lower. It was noted that, when the downstream lip was higher, the trapping efficiency was materially reduced. For simplicity in construction then, it is recommended that the two lips be at the same elevation.

Many of the existing field structures contain tubes that are tapered along the length L. According to Rohwer (10), straight tubes are equally as efficient in removing material. All of the tubes in the present tests were straight. Straight tubes are simpler to construct and install so that these are recommended. Tube shapes such as those shown in Table 1 for Rohwer series 6 and Robinson series 1 and 5 were very effective. Those made from commercially fabricated pipe (Robinson series 5) seem as effective as the others and are easily constructed. Shapes such as those shown in Table 1 for Rohwer series 1 through 3 have been widely used in existing field installations. However, Rohwer (11) noted that material was frequently thrown out of these, particularly at the higher channel velocities. This would result in material returning to the channel.

Tests made to determine efficiency of trapping when the outflow was controlled indicated that the efficiency would be reduced to some extent with a reduction in outflow. Reduction in translation velocity within the tube was used as a measure of this effect. The reduction in velocity was not in direct proportion to reduction in percentage of flow removed, however, so that if the flow was reduced by one-half, the velocity was only reduced a portion of this. With lower concentrations of bed load, it is possible that there was sufficient movement within the tube so that high removal efficiencies were maintained. The results shown in Fig. 7 indicate that translation velocity (V_p) was relatively constant for a range of mean channel velocities below a Froude number of 1. Beyond this point, the translation velocity increased rapidly.

Effect of material size on efficiency of trapping was noteworthy. Under optimum operating conditions, material of a size $>$ 0.83 mm was effectively trapped and removed. For material $<$ 0.30 mm, the trapping efficiency was very low, usually less than 35%. In general, those sizes greater than 0.50 mm

will be removed. Essentially, only that material that is moving at or near the bed will be trapped by the device.

The amount of sediment moving as bed load is of importance in the operation of the tube only for high concentrations. When the flow depth is great, relative to the width of opening, then the concentration should not exceed 0.20% (2,000 ppm) if optimum operation is to be maintained. For shallower depths, the concentration may reach 0.45%. In channels when the load may exceed these values, two parallel tubes should be installed.

The effect of velocity and depth of flow on the trapping efficiency are interrelated. Tests by Koonsman (3), shown in Table 4, indicated that the highest efficiencies existed near a Froude number of unity, that is at critical depth. The studies by Rohwer (10), given in Table 5, show that the efficiency generally increased as the Froude number increased. However, series 6 and 7 of these tests gave almost constant efficiencies for a Froude number range of 0.6 through 1.4. The results from the study being presented, as given in Table 3, indicate almost constant efficiencies for the entire Froude number range except for series 7 through 10. In general, when considering the Froude number alone it would seem that the range should be from 0.6 through 1.0. Values lower than this might result in the tube being inoperative whereas those higher would result in material being thrown out of the tube as well as the problems in scour downstream from the structure due to higher exist velocities.

As was discussed in the section on sediment transport, the section containing the vortex tube should be designed so that flow conditions are in the regime in which plane bed type of sediment movement will exist. This was found to be in a Froude number range of 0.6 to 0.7 for material with a mean size of 0.45 mm. Indications are that, for larger material, the Froude number must be increased to maintain the plane bed. For sand sizes $>$ 0.50 mm, it would seem that the velocities and depths of flow in the section should be in a range of Froude numbers between 0.7 and 0.9.

The relationship of efficiency to depth of flow for a range of Froude numbers was presented in Figs. 12 through 17. For lower values of Froude number, efficiency decreased rapidly as depth increased. For $\mathbf{F}$ in the range of 0.8 through 1.0 efficiency seemed to be almost independent of depth. Because most operating canals will generally have depths that are large relative to slot opening, it would seem that the section should be designed to maintain the 0.8 through 1.0 range.

The importance of maintaining the higher range of Froude number is also illustrated in Figs. 18 and 19. As the value of d/D increased, the Froude number must be increased to maintain higher efficiencies. At a d/D value of 4, the Froude number must be increased to 0.9 as compared to 0.7 for d/D equal to 3, to maintain an efficiency of 60% for material $>$ 0.83 mm.

There are other points to consider relative to design and location of the vortex tube section. Most of the structures now in existence have been located near canal headworks. Generally, they are located between the headworks and the measuring structure. In this manner, the extra amount of water necessary in the operation of the tube can be returned to the river before it reaches the measuring device in the canal. Sufficient grade is necessary in returning this flow together with the material that has been removed. A collection chamber needs to be provided outside the section such as shown in Fig. 4(a). A gate valve may be necessary to control flow from the tubes. This should be on the outlet from the chamber rather than from the tubes as shown in Fig. 4(a).

When used in an unlined canal, the section should be approximately the same width as the canal but with the bottom raised. Contracting the sides will lead to additional problems in bank scour downstream from the vortex tube section.

Problems may arise in determining the amount of rise to be provided in the bottom of the vortex tube section in order to maintain the Froude number of the flow near 0.8. For canals that operate at almost constant stage, the problem is simplified. For those in which the flow varies widely, a design flow should be selected that will exist for a greater portion of time. The amount of rise in the floor can then be determined for this design flow and normal depth. Flows greater than this design flow will result in Froude number less than 0.8, whereas those less than the design flow will increase the Froude number. In the latter case, the upstream depth will also be increased over normal depth to provide additional needed energy.

SUMMARY

Tests have been made on a type of bed load ejector termed the vortex tube sand trap. These tests have shown that the following design criteria are necessary for the successful operation of the device:

(1) The velocity and depth of flow across the section containing the tube should be such that the Froude number approximates 0.8.

(2) The percentage of flow removed by the tube is a function of the depth and velocity of flow in the channel as well as width of opening, area, angle, and length of tube. The flow removed usually ranges from 5% to 15% of the total.

(3) The width of opening should usually be in the range of 0.5 ft to 1.0 ft.

(4) The ratio of length of tube to width of opening (L/D) should not exceed 20 with the maximum length of tube being approximately 15 ft.

(5) The tube angle should be 45°.

(6) Straight tubes operate as well as tapered ones.

(7) The elevation of the upstream and downstream lips of the tube can be the same rather than having the downstream one lower.

(8) The shape of the tube does not seem to be particularly important as long as this shape is such that material entering the tube is not allowed to escape back into the channel. A pipe with a portion of the circumference removed seems to operate as well as other prefabricated shapes.

(9) The required area of the tube can be approximated by the relationship $A_T = 0.06\ D\ L \sin\theta$.

(10) With the foregoing design specifications, the tube can be expected to remove approximately 80% of the sediment with sizes greater than 0.50 mm. The trapping efficiency of smaller sizes will be considerably lower.

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12. "Theory and Design of Stable Channels in Alluvial Materials," by D.B. Simons, Colo. State Univ., Dept. of Civ. Engrg., Ft. Collins, Colo., Report CER 51 DBS 17, 1955.

13. "Theory and Design of Stable Channels in Alluvial Materials," by D.B. Simons and M.L. Albertson, Presented to the ASCE Hydr. Conference, Atlanta, Georgia, August 20, 1958, p. 49.

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APPENDIX II.—NOTATION

A_T = cross sectional area;

A = area of flow;

B = depth of tube;

C = concentration of sediment, G/Q;

c = coefficient of discharge due to tube geometry and approach velocity;

D = width of opening;

d_u = depth of flow upstream from tube;

d = depth of flow in channel at tube;

d_s = size of sand fraction;

E = efficiency of trapping;

$\mathbf{F}$ = Froude number;

G = total sediment discharge through channel;

G_T = sediment discharge through channel;

H = effective head;

L = length of tube;

P = difference in upstream and downstream lip elevations;

Q_T = water discharge through tube;

Q = channel discharge;

$\mathbf{R}$ = Reynolds number;

R = extractor ratio;

s = slope of channel;

s_e = slope of energy gradient;

V = mean velocity of flow immediately upstream from tube;

V_p = velocity of a particle along the tube, translation velocity;

W = width of vortex tube section;

Z = contraction ratio between the channel and section containing the vortex tube;

γ = specific weight of fluid;

θ = angle of tube to direction of flow;

λ = shape of tube;

μ = dynamic viscosity;

ρ_s = sediment density;

ρ = density; and

ω = fall velocity.

Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

LOS ANGELES WATER SUPPLY AND IRRIGATION[a]

By Samuel B. Morris,[1] F. ASCE

SYNOPSIS

Unique amongst major cities of the United States, Los Angeles California, after 100 yr as a small irrigation village, imported new water supplies 240 miles and expanded its irrigated area to afford early use for its aqueduct capacity. The 85,000 acres annexed to the city to secure irrigation water overlie the groundwater basin of the Los Angeles River. Irrigation thus caused replenishment of groundwater, increasing the city's water supply.

Rapidly, irrigation grew to a total of 63,000 acres, and by 1929, maximum water sales were 89,000 acre-ft. Since that year, especially since World War II, the irrigated lands have given way to homes and industries and only about 15,000 acres remain in irrigation. These last are remnants of irrigation within the city and are rapidly disappearing.

Cost of water to the irrigator in the old pueblo days of local water delivered through open irrigation ditches, compared with the subsequently imported supply of aqueduct water, brought hundreds of miles and delivered through steel pressure pipes, shows an increase from \$1.50 - \$2.50 per acre-ft to \$7.00 -

Note.—Discussion open until May 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the Copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 4, December, 1960.

[a] Presented at the February, 1959 ASCE Convention in Los Angeles, Calif.

[1] Cons. Engr., 1944-1955, Gen. Mgr. and Chf. Engr., Los Angeles Dept. of Water and Power.

$10.00 per acre-ft. Of interest, is the fact that in pueblo days, as now, the irrigator has paid only about one-half the cost of the water served him.

INTRODUCTION

The City of Los Angeles is unique among the major cities of the United States; for the 100 yr subsequent to its founding it was a small irrigation village. In telling this story, principal events that occurred during the period from the irrigation of the Spanish Pueblo by the waters of the Los Angeles River in 1781, to the construction of the 240-mile Los Angeles Aqueduct from the Owens River, from 1908 to 1913, and the annexation and irrigation of the San Fernando Valley in 1915, will be realted. This annexation of 108,732 acres followed an engineering report that the water used for irrigation on these otherwise dry lands overlying ground water would increase the flow of the Los Angeles River as well as afford an immediate market for the large, new water supply until urban population would require its full use.

HYDROLOGY

California is largely a semiarid state. Virtually all rain and snow in the high mountains fall during winter and early spring; practically none falls during summer and autumn. On an average, 70% falls in three winter months. In the extreme northwestern part of the state, rainfall exceeds 100 in. per yr. In the extreme southeastern area the rainfall is only 2 or 3 in. per yr. Los Angeles has an average of 15 in. of rain annually. Southern California, with 50% of the state's population, has less than 2% of the state's stream flow. Everywhere irrigation is required for maximum agricultural production.

There were, however, under natural conditions, before the advent of man's activities, intermittent flood flows from the high mountain ranges of the San Gabriel and San Bernardino Mountains. These waters flowed over the porous gravels and sands of their debris cones, causing deep percolation into large ground-water basins that lay between these mountains ranges and the lower Cahuenga Mountains, Puente Hills, and Santa Ana Mountains.

From these interior ground-water basins, rising water provided large perennial streams. Flow of the order of 50 cu ft to 100 cu ft per sec passed through three narrows in the low hills onto the broad coastal plain that extends from Santa Monica Bay to Newport Beach and Balboa. Here again, the water sank underground into the non-pressure forebay of this large coastal ground-water basin, made artesian by a rather continuous clay cap and an underground faulted and folded structure known as the Inglewood-Newport fault zone. Incidentally, this structural feature is in one of the important oil-producing areas of the South Coastal Basin and is the origin of occasional earthquakes.

Each of these alluvial-filled basins is of the order of 1000 ft or more in depth to the basement complex of older non-water-bearing formations. The three major rising streams, from west to east, are the Los Angeles River, the San Gabriel River, the Rio Hondo, and the Santa Ana River. Owing to the low slope of the lands and large debris load, these rivers have changed their

courses during flood stages. The Los Angeles River has alternately discharged into Santa Monica Bay at Ballona Creek and into San Pedro Bay. The San Gabriel River, Rio Hondo, and Santa Ana alternately swing over the remainder of the coast from San Pedro to Newport. This paper is concerned mainly with the Los Angeles River, that has a drainage area above its narrows at Elysian Park of 317 sq miles of mountain and foothills and 194 sq miles of valley, making a total drainage area at the Narrows of 511 sq miles.

Rainfall at Los Angeles averages 15 in., but has varied from a maximum of 38.18 in. to a minimum of 5.59 in. Rainfall increases with altitude from about 10 in. to 12 in. at the coast line to an average of more than 40 in. in some high mountain areas. During most of the season there is no continuous flow from the mountain area to join with rising water at the Narrows. During periods of heavy rainfall, floods may exceed 50,000 sec.-ft. The 1938 flood, that caused many millions of dollars of damage, and the loss of 80 lives in Southern California, reached a peak flow at the Los Angeles River Narrows of 68,000 sec.-ft.

EARLY HISTORY

On October 8, 1542, just half a century after Columbus discovered America, the Spanish explorer Juan Rodriquez Cabrillo dropped anchor in San Pedro Bay, now Los Angeles Harbor. Little about this area was recorded for the next 225 yr until Don Caspar de Portola, on his march northward from San Diego seeking Monterey, camped at Sycamore Grove on the banks of the Arroyo Seco "dry creek", on August 1, 1769. The following day he and his men pitched their tents on the east bank of a clear stream that they named Rio de la Porciuncula, because this was August 2, the day of the great Indulgence of our Lady of Los Angeles of Porciuncula, the name of the Chapel of St. Francis in Assisi, Italy. The river was our present Los Angeles River, and the spot they camped upon that day was on the eastern bank, about where the North Broadway bridge crosses the river.

Portola and his force of 64 men were the first white men ever to set foot upon the site of the present city of Los Angeles. The entry in Father Crespi's diary of this expedition was prophetic:

> Wednesday, August 2—We set out from the valley in the morning and followed the same plain in a westerly direction. After traveling about a league and a half through a pass between low hills, we entered a very spacious valley, well grown with cottonwoods and alders, among which ran a beautiful river from the north-northwest, and then, doubling the point of a steep hill, it went on afterwards to the south. Toward the north-northeast there is another river bed which forms a spacious water course, but we found it dry. This bed unites with that of the river, giving a clear indication of great floods in the rainy season, for we saw that it had many trunks of trees on the banks. We halted not very far from the river named Porciuncula. Here we felt three consecutive earthquakes in the afternoon and night. We must have traveled about three leagues today. This plain where the river runs is very extensive. It has good land for planting all kinds of grains and seeds, and is the most suitable site of all we have seen for a mission, for it has all the requisites for a large settlement.

"As soon as we arrived about eighteen heathen from a good village came to visit us; they live in this delightful place among the trees on the river."

How long the little Indian village of Yang Na had existed, no one knew. The next day they marched past the now famous La Brea pits, from whose tar so many perfectly preserved skeltons of mastodons, saber-toothed tigers, giant sloths, and numerous other prehistoric animals have been excavated. The rather violent earthquakes observed by de Portola gave early warning that all engineering construction should be earthquake resistant.

On September 4, 1781, Felipe de Neve, with a detachment of soldiers bearing the banner of Spain, led a little band of 44 settlers, composed of 11 men, 11 women, and 22 children, to found El Pueblo de Nuestra Senora la Reina de Los Angeles on lands adjacent to the Rio de la Porciuncula.

Of greatest value to the pueblo and its successor was the act of King Carlos III of Spain that was born of the custom prevailing in Spain's semiarid lands, in granting to the pueblo all of the waters of the Rio de la Porciuncula. Many have been the jokes about this upside-down Los Angeles River, but it has been and still is a very valuable asset to Los Angeles.

The first settlers drew lots for ground around the plaza on which to build their adobe huts. They constructed open ditches to convey water to the pueblo and to the ranch lands that they irrigated. The main ditch was the Zanja Madre, and all ditches were in charge of "zanjeros," or ditch tenders. This ditch system was always owned and operated by the pueblo, and later by the city of Los Angeles. The ditches reached their heyday in the mid-1880's a hundred years after the pueblo's founding. Early authors have written of the beauties of Los Angeles of this period with its many ditches lined with trees and shrubs bearing beautiful flowers and luscious fruits.

In 1835 the Mexican Congress, succeeding to the authority of Spain, had raised the pueblo to the status of a city (ciudad de Los Angeles) and named it the capital of Alta California, the territory that was to be lost to the forces of Gen. John C. Fremont only 13 yr later. For a brief period, California was an independent state under the Bear Flag. A city council was installed January 1, 1848, and two years later the United States Census Bureau recorded a population of 1,610 whites, with probably about as many Indians. On April 4, 1850, the legislature, meeting in San Jose, incorporated the city of Los Angeles.

EARLY ZANJA IRRIGATION SYSTEM

The original thirty fields of 30,000 sq varas to 40,000 sq varas (5.3 acres to 7.1 acres), each laid out at the founding of the pueblo in 1780, grew in the 107 yr to an irrigated area of 6,898 acres in the city and 4,239 acres outside, or a total of 11,136 acres.

The zanja system grew to 52 miles in the city, of which 32.5 miles were in open ditches. Outside the city, the zanjas extended an additional 40 miles, making a total of 92 miles. The cost was of the order of half a million dollars. The zanjeros supervised the sale of irrigation water that was delivered in nominal "irrigation heads" of 100 miners in. (2.0 cfs).

The water charges in 1870 were $1.50 per day, or $1.00 per night for a head of 100 miners in., from March 1 to October 1. During the months from Octo-

ber through February, the rate was $0.75 by day. There was no charge at night. By 1888, the rates were $3.00 per head per day, from sunrise to sunset, $2.00 per half day, and $3.50 per hr overtime. Outside the city, the rates were $5.00 per day and $3.00 per night. In that time, the operating and maintenance costs of the zanja system ran $10,000 to $11,000 per year, with revenues of about the same amount. In addition, interest on water bonds ran slightly over $15,000 in the year 1888. In more modern terms, these rates for day irrigation use in the city varied from $1.50 to $2.50 per acre-ft, compared to present gravity irrigation rates of $10.00 per acre-ft. It should be noted that irrigation rates from the modern pressure distribution mains, with 240-mile to 300-mile importation of water, have increased to 4.0 to 6.7 times those in effect from the old Zanja Los Angeles River of the 1880's. Oddly, irrigation in the city 60 yr ago enjoyed the same subsidy of about 50% of its cost.

EARLY SOUTHERN CALIFORNIA ECONOMY

Aside from irrigation at the Franciscan Missions located near cienegas, or rising perennial streams, there was little irrigation elsewhere in Southern California until the large Spanish land grants were broken up in the 1870's and 1880's by a combination of years of critical drought and the advent of the railroads. The latter brought about the "great land boom" with subdivisions into town lots.

The economy up to this early period in California had been based upon the raising of cattle and sheep for their hides and tallow and the discovery of gold in 1849.

DOMESTIC WATER SYSTEM

The horse-drawn barreled water that served the customers' "ollas" with domestic water to supplement the zanjo irrigation system, shortly after American dominion, gave way to a city-owned water distribution system of bored wooden logs. The City Council, tired of the high maintenance cost and poor service of domestic water works leased the works to the Los Angeles City Water Company in 1868 for a period of 30 yr. The city continued to retain the zanja system.

Nearing the end of this 30-yr lease, the private water company engaged more actively in politics than in giving good service. The citizens revolted, and by a majority of 5-to-1, voted $2,000,000 in bonds to purchase the private water system serving a population of over 100,000 people.

And thus, in 1902, during a critical 11 yr dry period extending from 1893 to 1904, the city of Los Angeles became the owner of the domestic water works and continued in the ownership of the zanja irrigation system. Heading both domestic and irrigation works was William Mulholland, Chief Engineer, who had, for 14 yrs, been superindendent of the Los Angeles City Water Company.

Mulholland was a self-taught Irish immigrant who rapidly rose from a laborer to a great leader of men, an engineer of vision and faith in the destiny of his adopted community. The zanja system was brought into the new Water Department, but by 1904, subdivision of lands, lack of use, and high cost of what little remained caused the abandonment of these irrigation ditches that

had contributed so much to the economy, beauty, and charm of early Los Angeles.

LOS ANGELES AQUEDUCT

Mulholland, encouraged by a reconnaissance trip to Owens Valley with Fred Eaton, formerly Chief Engineer of the Water Company, City Engineer, and Mayor of Los Angeles, soon recommended to his Board of Water Commissioners that the city of Los Angeles acquire rights to the Owens River draining the east flank of the Sierra Nevada Mountains and construct a 240 mile, 400 cfs (258 mgd) aqueduct to divert this water to Los Angeles. With a population of 200,000, as of 1905, he forecast a far greater population than the 400,000 he estimated could be served by the Los Angeles River. He declared that it would be unwise for Los Angeles to develop nearby sources of water needed for growth of neighboring communities. The importation of Owens River water would enable the city to grow to a population of 2,000,000.

His report and estimates of cost, $1,500,000, for lands and water rights, and $23,000,000 for construction of the aqueduct were concurred in by a board of eminent consulting engineers composed of John R. Freeman, and Frederick P. Stearns, former Presidents, and James Dix Schuyler, former Vice President of ASCE. Pleading for the then-unprecedented aqueduct bond issue for so small a city, Mulholland said, "If you don't build it you won't need it." The citizens had confidence and voted nearly 10-to-1 in favor of the aqueduct bonds, in two issues. The aqueduct construction was completed in 1913, and within the estimated cost.

IRRIGATION OF SAN FERNANDO VALLEY

Soon it became apparent that such a large water supply could not be absorbed quickly by the growing water demands of domestic and industrial users. There were many proposals. The one that was adopted was the recommendation of a consulting board composed of John H. Quinton, William H. Code, and Homer Hamlin, all Members, ASCE.

The report recommended irrigation of 120,000 acres of land in San Fernando Valley overlying ground water tributary to the Los Angeles River. It is of interest to quote from this report, referring to the San Fernando Valley, the report states:

> The Valley ". . .may be likened to a huge bowl, slightly tipped on a horizontal table, so that its rim is in a sloping instead of a horizontal plane. If all of the alluvium were removed from this bowl, it would appear as a great natural reservoir, created by Nature for the express purpose of holding the water of Owens River until needed by the City of Los Angeles. The fact that it is now partially filled up with a sponge of porous material, gravel, sand, etc., does not by any means destroy its usefulness as a reservoir, but the porous sponge does reduce its capacity. The alluvium of this bowl is now partially filled with ground water, that is, water which sinks into the gravel, sand, etc., from the surface streams entering the valley, but it will hold or store much more water.

"If, for example, all of the water from the Aqueduct were poured on the sands and gravels of the Tejunga wash, near the north end of the San Fernando Valley, it would probably all sink into the sponge of porous material, for some months at least. It would, however, flow undergound and eventually, after some time, reach the Los Angeles River, where it would flow on the surface again. When water is spread over the entire surface of the valley by irrigation, the whole mass of porous material, alluvium, will become a reservoir for the water which is not used up by evaporation, or by the growth and transpiration of plants. Some of the water used for irrigation is sure to sink deep into the ground, and we estimate that at least one-fourth of all the water used in the San Fernando Valley will eventually return to the Los Angeles River as underflow, and can be utilized a second time.

"This water is just as valuable as water direct from the Aqueduct. On account of the reutrn water, and for other reasons, it is highly desirable that the San Fernando Valley should have an adequate allowance of water for irrigation. The San Fernando Valley is the only place where water can be used in territory contiguous to Los Angeles which admits of the economical handling of return water. In all other areas the return water must be pumped to higher land."

The recommendation was approved. At an earlier date the Supreme Court had held that the city of Los Angeles, as successor to the Spanish Pueblo of 1781, was the owner of the Los Angeles River, both surface and underground. Accordingly, the city expressed willingness to provide irrigation water to the San Fernando Valley only after its annexation to the city of Los Angeles. And so, on May 22, 1915, practically all of San Fernando Valley, except areas then or since incorporated into the cities of San Fernando, Burbank, and Glendale was annexed to Los Angeles. It is believed that substantially all territorial growth of Los Angeles from an original incorporation of 28.01 sq miles to its present area of 456.61 sq miles has been done in order to participate in the city's water supply ; this is with exception of the annexation in August, 1909, of the cities of Wilmington and San Pedro, with a combined area of 14.54 sq miles, whose principal purpose was the development of the Los Angeles Harbor.

And, thus again, irrigation that contributed so much to Los Angeles' founding and growth for 130 yr had a new and larger expansion. The San Fernando land owners, having 87,215 acres, were required to pay the cost of distributing mains, amounting to about $3,000,000, or $34.40 per acre. Water Districts were incorporated in 1914, and lines were rapidly constructed of low-cost thin riveted steel pipe, dipped in asphalt, and laid with a scarfed slip joint. There were 307 miles of these pressure irrigation mains, costing an average of only $1.85 per ft of pipe. The slip joints depended for tightness entirely on their close fit and asphalt. The large transmission lines had riveted joints.

Irrigation in San Fernando Valley grew rapidly. The system was 100% metered. Irrigators were required to take water on rotating schedules, including irrigation at night. By 1925, there were 58,000 acres irrigated. Water used was 63,000 acre-ft, equivalent to an average depth of applied water of only 1.09 ft. The maximum water sales were in 1929, when 89,000 acre-ft were used on 53,000 acres, a duty of 1.67 ft depth of applied water. Since that time,

increased population and industry have encroached upon irrigation in the Valley. The 1957 and 1958 annual report shows total water sales for intermittent irrigation was only 24,200 acre-ft, indicating that the irrigated area had shrunken from a maximum of 58,000 acres to about 15,000 acres. The present area irrigated is somewhat larger than the area irrigated during the heyday of the old zanja system.

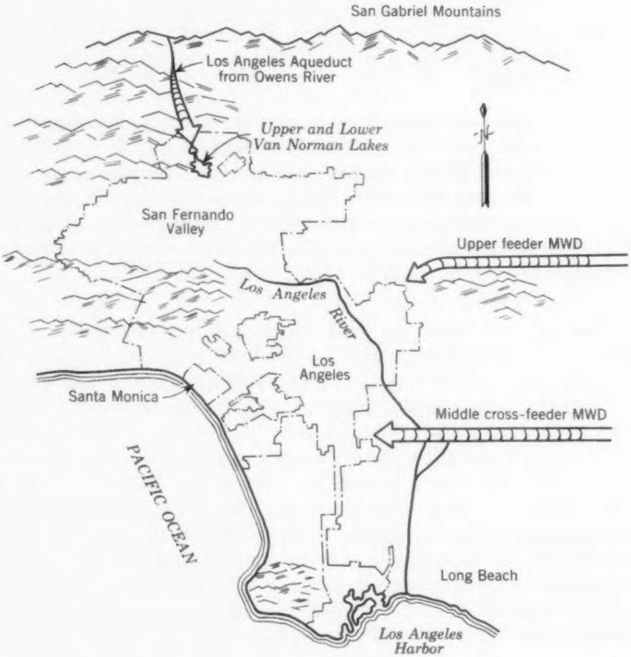

FIG. 1

During the years, the Los Angeles Aqueduct plus the Los Angeles River and local sources produced water in excess of requirements, and irrigation water sales produced additional water revenues, even though the rates approximated only $7.00 per acre-ft. However, as total water demands have grown, and Los Angeles has had to purchase water from the Metropolitan Water District of Southern California (Fig. 1) at $20.00 or more per acre-ft, it is obvious that the present charge of $10.00 per acre-ft is less than half the cost of water to the department.

WATER SPREADING

From 1932 to 1952, while the Aqueduct provided excess capacity, the Department spread Los Angeles Aqueduct water on specially prepared spreading

grounds to further replenish the ground water of the Los Angeles River for the city's later use. During the maximum year, 33,000 acre-ft were spread. Water has not been spread since 1952, except for minor regulation of the system, as water demands and surface storage have been sufficient to utilize the full capacity of the Aqueduct.

CONCLUSION

In conclusion, irrigation has contributed to the economic development of Los Angeles for the entire 177 yr since the founding of the Spanish Pueblo until it has grown to a great commercial and industrial city of 2,400,000 people. Whereas intermittent irrigation from the Los Angeles Aqueduct has been regarded as the interim use of surplus capacity, the city has not withdrawn any water from irrigation use, but, rather has sought additional water supplies. The department extended its diversions to Mono Basin, 338 miles to the north, and the city of Los Angeles joined with other cities to form the Metropolitan Water District of Southern California to construct the Colorado River Aqueduct, first put in use in 1941. The Department of Water and Power is now urging the State's Feather River Project to bring additional water to Los Angeles and Southern California.

Expanison of population and industry has, fortunately, occupied the formerly irrigated lands, bringing greater economy to the city of Los Angeles, now the nation's third most populous city.

The irrigation chapter within the city of Los Angeles is about to close after 177 yr of important contribution to the life and welfare of the people of Los Angeles in its growth from a sleepy Spanish and Mexican village to become the heart of this metropolitan community of 6,450,000 people, that may have already become second only to New York.

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METHOD FOR ESTIMATING CONSUMPTIVE USE OF WATER FOR AGRICULTURE

By Wendell C. Munson,[1] F. ASCE

SYNOPSIS

Estimates of monthly and annual consumptive use of water for agriculture are essential for the planning of potential irrigation projects. Formulas have been developed which consider complex functions of the many variables involved and result in mathematically exact computations of evapotranspiration which may vary considerably among the different formulas, depending upon the researchers' evaluation of the various factors involved.

It is the purpose of this paper to present data on measured rates of consumptive use of water as well as estimated consumptive use determined by various formulas and to describe a procedure for determining monthly and annual water requirements, on a project basis, from climatological data for areas where measurements of consumptive use are not available. The simple method for estimating consumptive use of water for agriculture is called the Precipitation-Evaporation or P. E. Index Method.

INTRODUCTION

Planning for the optimum utilization of available water supplies involves consumptive use of water as its basic precept for the future development of any area, whether it be for irrigation, flood control, power, municipal uses, or for multiple purposes. Consumptive use, or evapotranspiration, includes all

Note.—Discussion open until May 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 4, December, 1960.

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evaporation and transpiration losses from lands where there is vegetative growth, plus evaporation from water surfaces and from unvegetated lands. Factors affecting the rate of evapotranspiration include: moisture supply; cropping practices; soil types and infiltration rates; drainage conditions; within project climatic variations; topography; and soil treatment methods.

When accurate measurements of precipitation and runoff are available, it is possible to obtain values of the combined losses due to evaporation and transpiration by simple subtraction. However, when analyzed it is evident that there is a joker in the words, "accurate measurements." Precipitation is not only erratically distributed in time, but is unevenly distributed in space, particularly on a storm basis. Squall line storms, typical of warm front activity, vary tremendously in amounts over short distances. Such storms have been known to vary in amount a few inches per mile distance from the "eye."

The Weather Bureau rain gage network is not dense enough to portray adequately amounts, intensities and durations of squall line, and convection storm precipitation. Even research networks (one gage per square mile, or less) of small watersheds leave considerable doubt as to actual watershed rainfall, for short periods of time. It is thus evident that the accuracy of precipitation measurements, even over small areas, is subject to wide variations. The accuracy of rain gages varies considerably depending on height above ground level. Rainfall catch at ground level may be from 5% to as much as 30% greater than shown by gages located from 12 in. to 18 in. above ground level as stated by E. J. Winter[2] and G. F. Makking[3] at a meeting of the International Association of Scientific Hydrology in September, 1959.

Measurements of runoff vary considerably in accuracy, ranging from "excellent" (less than 5% error) to "poor" (more than 15% error). There are usually small unmeasured channels where significant amounts of surface water can escape and then there is the unmeasured ground water which precludes accurate measurements of runoff from any sizeable area. It is thus evident that a measure of evapotranspiration by the "inflow-outflow" method is subject to a considerable degree of variation.

Consumptive use is the basis for estimating project water demands. It represents the amount of water required to mature a crop, including precipitation and available soil moisture. Irrigation requirement includes consumptive use, adjusted for farm application efficiencies. Diversion requirements include the irrigation requirement adjusted for conveyance efficiencies. The wide range in estimated delivery and application efficiencies, coupled with the various factors affecting the rate of evapotranspiration, gives rise to the question voiced by C. P. Christopoulos of the University of Thessaloniki, Salonika, Greece: "What's the use of knowing exactly the true needs of plants for water when we apply to the lands wastefully and harmfully much more ?"[4]

This paper is concerned with the aspects of irrigation requirements based on purely physical factors. However, it should be borne in mind that economic factors are also extremely important and in many instances are the controlling factors in how much, and when, irrigation water is applied. Whenever the cost of labor needed to apply the water is relatively high compared to the cost of the

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[2] "Lysimetry at the National Vegetable Research Station Wellesbourne (Warvik, England)," by E. J. Winter.

[3] "Limitations and Perspectives of Lysimeter Research," by G. F. Makking.

[4] "Monthly Consumptive Use Requirements for Irrigated Crops," by Harry F. Blaney, Proceedings, ASCE, Vol. 85, No. IR 1, March, 1959. Discussion by Constantine Christopoulos, December, 1959.

water, the economic efficiency of application takes on greater significance in relation to the physical efficiency of application. The returns received for any commodity must of necessity exceed the cost of production. There are instances where so-called "poor" irrigation practices which are physically wasteful of water will yield a higher net monetary return per acre than "good" irrigation practices.

This is mentioned at this time lest we become too engrossed about solving the physical aspects of water requirements for irrigation and forget that mathematics is a universal subject which applies to economic factors as well as to physical factors.

Many of the evapotranspiration data have been gathered from greenhouse pots and small plots and are not suitable for field interpretation as they do not consider the myriad of intricate and inherent factors of great import. A few of these are: variety of individual crop; cropping practices; quality of water; homogeneity of project soils; harvesting methods; drainage conditions; homogeneity of ground-water conditions; within project climatic variations; infiltration rates of various project soils; and soil treatment methods.

What is the amount of the water requirement for a certain crop? Will the same amount of water be required for different varieties of the same crop? Is this the amount of water required to keep soil moisture above the wilting point or at field capacity? How much variation will there be in yield under different planting or harvesting methods, different water table conditions, and so forth? Assuming all these conditions to be known as well as the first year's cropping pattern, what assurance do we have that this certain pattern will continue on this project? If we have 1,000 acres of alfalfa, what assurance do we have that the requirement will apply equally to each acre in the field? These are but a few of the unanswered or unanswerable questions relating to project consumptive use. Because of the great amount of time involved in attempting to compute the influence of these many factors, the P. E. Index Method was devised to provide a simple, rapid method for estimating project consumptive use and still give a result of sufficient accuracy to warrant its use in project formulation.

P. E. INDEX METHOD

During the 1930's, C. W. Thornthwaite developed a formula which he used to classify climate.[5] For every station where monthly observations of precipitation and temperature have been made it is possible to compute the monthly P. E. (Precipitation-Evaporation) ratios and the annual P. E. (Precipitation-Evaporation) Index, which thus becomes an evaluation of the effectiveness of precipitation. The quotient P/E is called the P. E. ratio and the sum of the twelve P. E. ratios is called the P. E. Index. Thornthwaite developed a nomogram by which he was able to read directly the P. E. ratios when the average monthly precipitation and temperatures were known (Fig. 1).

During the early 1940's, the writer found that crop yields followed a pattern paralleling the P. E. indexes. It was also apparent that if the annual P. E. Index approximated 48, crop production was adequate with the normal precipitation pattern of eastern Nebraska and western Iowa. Subsequently, many weather

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5 "The Climates of North America According to a New Classification," by C. W. Thornthwaite, Geographical Review, Vol. 21, 1931.

FIG. 1.—PE INDEX CHART

stations over the Missouri River Basin and western Iowa were studied and a set of representative monthly P. E. ratios were determined. Then, by using the average monthly temperatures and the assumed P. E. ratios, it was just a matter of reading from the Thornthwaite nomogram to determine readily the required precipitation, or actually the consumptive use requirement, for crop production on an area basis. After some years of study of weather and crop data from irrigated areas over the Western United States, the writer arrived at a set of P. E. ratios which were adequate for normal plant growth at any of the many stations studied. They are:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1.0	1.8	3.2	4.4	5.8	6.0	6.8	6.1	4.6	3.5	2.3	1.5	47.0

Table 1 was prepared for each of the twelve months based on the Thornthwaite formula (Eq. 1) and the preceding P. E. ratios.

$$\log \frac{P}{E} = \log 115 + \frac{10}{9} \log P - \frac{10}{9} \log (T - 10) \quad \ldots\ldots\ldots \quad (1)$$

in which T is the average monthly temperature in degrees F and P is the average monthly precipitation in inches. The limits for plant growth are assumed

TABLE 1.—P. E. INDEX TABLE

	January P/E = 1.0	February P/E = 1.8	March P/E = 3.2	April P/E = 4.4	May P/E = 5.8	June P/E = 6.0	July P/E = 6.8	August P/E = 6.1	September P/E = 4.6	October P/E = 3.5	November P/E = 2.3	December P/E = 1.5
28.4	0.26	0.42	0.70	0.98	1.20	1.24	1.44	1.37	1.03	0.76	0.56	0.36
30	0.28	0.47	0.78	1.08	1.34	1.39	1.59	1.51	1.14	0.85	0.62	0.40
32	0.31	0.52	0.86	1.18	1.48	1.53	1.75	1.65	1.25	0.94	0.67	0.44
34	0.34	0.57	0.94	1.29	1.62	1.68	1.90	1.78	1.36	1.02	0.73	0.48
36	0.36	0.62	1.02	1.39	1.75	1.82	2.06	1.92	1.46	1.11	0.78	0.52
38	0.39	0.67	1.10	1.49	1.89	1.96	2.21	2.06	1.57	1.19	0.84	0.56
40	0.42	0.71	1.19	1.59	2.03	2.11	2.36	2.19	1.68	1.28	0.89	0.60
42	0.45	0.76	1.27	1.69	2.17	2.25	2.52	2.33	1.78	1.37	0.95	0.65
44	0.48	0.81	1.35	1.80	2.30	2.40	2.68	2.47	1.89	1.46	1.01	0.69
46	0.51	0.86	1.43	1.91	2.44	2.54	2.83	2.60	2.00	1.55	1.07	0.73
48	0.53	0.90	1.51	2.01	2.58	2.66	2.99	2.73	2.10	1.64	1.13	0.77
50	0.56	0.95	1.59	2.12	2.72	2.80	3.14	2.87	2.21	1.73	1.18	0.81
52	0.59	1.00	1.67	2.22	2.85	2.94	3.30	3.00	2.32	1.82	1.24	0.85
54	0.62	1.04	1.75	2.33	2.99	3.08	3.45	3.14	2.43	1.90	1.30	0.89
56	0.65	1.09	1.83	2.44	3.12	3.23	3.61	3.28	2.54	1.98	1.36	0.93
58	0.68	1.14	1.91	2.54	3.26	3.38	3.77	3.42	2.65	2.07	1.42	0.97
60	0.71	1.19	1.99	2.65	3.40	3.52	3.92	3.56	2.76	2.16	1.48	1.01
62	0.74	1.24	2.07	2.76	3.53	3.66	4.07	3.70	2.88	2.24	1.54	1.05
65	0.77	1.29	2.15	2.86	3.66	3.79	4.23	3.84	2.99	2.32	1.60	1.10
66	0.80	1.34	2.23	2.97	3.80	3.93	4.39	3.98	3.10	2.41	1.66	1.14
68	0.83	1.39	2.31	3.08	3.94	4.07	4.54	4.13	3.21	2.50	1.72	1.18
70	0.87	1.44	2.39	3.19	4.08	4.21	4.69	4.27	3.32	2.59	1.78	1.22
72	0.89	1.49	2.47	3.30	4.22	4.35	4.85	4.41	3.43	2.68	1.84	1.26
74	0.92	1.54	2.55	3.41	4.36	4.49	5.02	4.56	3.54	2.77	1.90	1.30
76	0.95	1.59	2.63	3.52	4.50	4.63	5.18	4.70	3.65	2.86	1.96	1.35
78	0.98	1.64	2.71	3.63	4.64	4.77	5.34	4.84	3.76	2.95	2.02	1.39
80	1.01	1.69	2.79	3.74	4.78	4.91	5.49	4.98	3.87	3.04	2.08	1.43
82	1.04	1.74	2.87	3.85	4.92	5.05	5.65	5.12	3.98	3.13	2.14	1.47

to be 28.4 F and 100 F. To determine project consumptive use for any month all that is necessary is the average monthly temperature for that month. Then, the monthly consumptive use can be read directly from Table 1 for that month, as shown in Table 2. To determine the consumptive use requirement for January, obtain the average monthly temperature in degrees Fahrenheit, or 31.2°. Then look under 31.2 in the P. E. Index (Table 1) for January and read directly, 0.30 in. The corresponding monthly consumptive use requirements are obtained from their corresponding monthly tabulations in a similar manner.

The P. E. Index Method is based on actual field conditions over county-wide areas and thus most of the vagaries or intangibles such as climatic patterns, wind movement, humidity, cropping patterns, crop varieties, farmer's idiosyncrasies, topographic variations, etc., received a true measure of consideration in the normal crop production sequence. In other words, by the determination of the effective P. E. ratios for adequate crop production without irrigation, from field conditions, the many intangibles were bypassed.

This method is accurate, rapid, and simple. It gives the monthly and annual requirements directly. As is the case with any theoretical formula, it is necessary to exercise judgment in the use of this method. Additional refinement will doubtless be necessary, and experience may show that the assumed P. E. ratios may require some adjustment to adapt them to conditions peculiar

TABLE 2.—SAMPLE COMPUTATION, VALSETZ, OREGON

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
T°F.	31.2	39.4	41.9	46.3	51.9	58.9	63.8	64.6	61.1	49.1	49.9	39.2	
P.E.(in.)	0.30	0.70	1.26	1.92	2.85	3.44	4.21	3.88	2.84	1.69	1.17	0.59	24.85
P.E.(ft)	0.02	0.06	0.10	0.16	0.24	0.29	0.35	0.32	0.24	0.14	0.10	0.05	2.07

to some areas. However, for project formulation purposes where cropping practices are estimated, farm efficiencies are estimated, canal and lateral losses are estimated, and future operator's idiosyncrasies are indeterminable, it appears that the adoption of such a simple, rapid, and reasonably accurate method of estimating project consumptive use, such as the P. E. Index method, should be given serious consideration. An evaluation of the P. E. Index method is given in the following examples:

CONSUMPTIVE USE REQUIREMENTS BY VARIOUS FORMULAS

Lowry-Johnson Method.[6]—The Lowry-Johnson method utilizes accumulated heat units in day-degrees above 32 F, which are applied to an empirical curve to determine annual consumptive use. Monthly distribution of the annual estimate is usually made by comparison with monthly evaporation rates. Table 3 illustrates the results obtained by the Lowry-Johnson and P. E. Index methods for the Coburg Area and Merlin Division, Oregon.

The Coburg Area is located in west-central Oregon, in the Willamette River Basin and the Merlin Division is located in southwestern Oregon, in the Rogue River Basin.

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[6] "Consumptive Use of Water for Agriculture," by Robert L. Lowey, Jr. and Arthur F. Johnson, Transactions, ASCE, Vol. 107, October, 1942.

TABLE 3.—ESTIMATED CONSUMPTIVE USE IN FEET

Method	Winter	April	May	June	July	Aug.	Sept.	Oct.	Annual
(a) Coburg									
Lowery-Johnson	0.39	0.22	0.27	0.35	0.45	0.43	0.26	0.13	2.50
P. E.	0.39	0.20	0.27	0.31	0.37	0.34	0.25	0.17	2.30
(b) Merlin Division									
Lowery-Johnson	0.22	0.27	0.29	0.36	0.47	0.47	0.33	0.07	2.48
P. E.	0.39	0.26	0.28	0.32	0.38	0.35	0.25	0.10	2.33

TABLE 4.—ESTIMATED CONSUMPTIVE USE IN FEET

Method	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
(a) Brevard, North Carolina													
Thornthwaite	.01	.01	.07	.15	.25	.34	.37	.34	.24	.15	.05	.01	1.99
P. E.	.03	.05	.10	.17	.26	.31	.36	.33	.24	.15	.07	.04	2.11
(b) Siletz River Basin, Oregon													
Thornthwaite	.03	.04	.08	.13	.21	.29	.36	.35	.26	.13	.11	.04	2.03
P. E.	.02	.06	.10	.16	.24	.29	.35	.32	.24	.14	.10	.05	2.07
(c) Richmond, Virginia													
Penman	.06	.11	.17	.26	.35	.40	.40	.34	.26	.16	.09	.05	2.65
P. E.	.03	.06	.12	.20	.32	.38	.44	.39	.28	.17	.10	.05	2.54
(d) Raleigh, North Carolina													
Penman	.07	.12	.17	.28	.35	.41	.39	.34	.27	.16	.10	.06	2.72
P. E.	.04	.07	.14	.22	.33	.39	.45	.40	.28	.18	.10	.06	2.66
(e) Yuma, Arizona													
Blaney-Criddle	.12	.20	.28	.35	.45	.48	.35	.34	.31	.19	.09	.08	3.24
P. E.	.05	.10	.16	.25	.39	.43	.53	.49	.35	.24	.13	.08	3.20
(f) Torrington, Wyoming													
Blaney-Criddle	.04	.05	.05	.12	.32	.43	.46	.44	.16	.08	.06	.04	2.25
P. E.	.02	.04	.07	.15	.29	.32	.38	.36	.25	.14	.07	.03	2.12

TABLE 5.—RELATION BETWEEN BLANCY-CRIDDLE AND P.E. INDEX METHODS FOR ESTIMATING CONSUMPTIVE USE OF WATER FOR AGRICULTURE - MESA, ARIZ., 1945-1946

Item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Unit Inches Season	Unit Inches Annual
(a) Alfalfa[a]														
Measured C. U.	1.0	2.0	3.5	5.0	6.5	9.0	12.0	10.1	6.0	4.0	3.0	2.0	51.0	64.1
Cons. Use (k)	.29	.55	.74	.84	.91	1.14	1.36	1.20	.87	.73	.78	.57	...	...
Project C.U.-P. E.	.54	1.00	1.86	3.05	4.31	5.07	6.23	5.67	4.00	2.53	1.32	0.83	28.74	36.41
Adjusted P. E. (alf.)[b]	1.0	1.8	3.3	5.4	7.6	9.0	11.0	10.0	7.1	4.5	2.3	1.5	51.0	64.5
(b) Cotton														
Cons. Use (k)	...	...	...	.30	.40	.60	.80	.80	.70	.60	...	...	...	...
Blaney-Criddle C.U.	...	...	...	1.8	2.9	4.8	7.0	6.7	4.8	3.3	...	...	31.3	...
P.E.-C.U.[c]	...	...	...	1.9	3.3	4.7	6.5	6.7	5.7	3.7	...	...	32.5	...
(c) Soy Beans														
Cons. Use (k)	...	...	...	...	...	.35	.60	.90	.80	.50	...	...	...	...
Blaney-Criddle C.U.	...	...	...	...	...	2.7	5.3	7.6	5.5	2.7	...	...	23.8	...
P.E.-C.U.[c]	...	...	...	...	...	2.8	4.8	7.5	6.5	3.1	...	...	24.7	...
(d) Guar														
Cons. Use (k)	...	...	...	...	...	...	.30	.80	.80	.55	...	...	...	...
Blaney-Criddle C.U.	...	...	...	...	...	...	2.6	6.7	6.2	3.0	...	...	18.5	...
P.E.-C.U.[c]	...	...	...	...	...	...	2.4	6.7	6.5	3.4	...	...	19.0	...

[a] Rest period for alfalfa from August 1 to September 15.

[b] 51.0 divided by 28.74 = 1.77 (crop density factor). Project C. U. by P. E. method multiplied by the density factor gives the adjusted figure for alfalfa.

[c] Adjustment factor = (k) for crop divided by (k) alfalfa times P.E. consumptive use for alfalfa.

Thornthwaite Method.[7]—The Thornthwaite method utilizes mean monthly temperatures to determine monthly head indexes for a certain weather station. The unadjusted values of potential evapotranspiration are determined from a nomogram and then corrected for the percentage of daytime hours. The resultant monthly evapotranspiration figures represent the consumptive use requirements. Table 4(a) and (b) shows the results obtained by the Thornthwaite and P. E. Index methods for Brevard, N. C., and the Siletz River Basin in northwestern Oregon. The data for the Siletz River Basin was based on weather records at Valsetz, Oregon, near the center of the basin.

Penman Method.[8]—The Penman method is based on an estimate of radiative energy and includes corrections for windspeed, relative humidity, sunshine percentages, and uses a reflection coefficient. Table 4(c) and (d) shows the results obtained by the Penman and P. E. Index methods for Richmond, Va., and Raleigh, N. C.

Blaney-Criddle Method.[9]—The Blaney-Criddle method utilizes mean monthly temperatures, monthly percent of daytime hours, and a predetermined consumptive use coefficient for individual crops. Table 4(e) and (f) shows the results obtained by the Blaney-Criddle and P. E. Index methods for Yuma, Ariz., and Torrington, Wyo.

The consumptive use estimates computed by the Blaney-Criddle method made use of individual seasonal crop coefficients (k). For some crops the monthly coefficients are more or less uniform throughout the season while on other crops the monthly coefficients may cover a wide range. To evaluate better the relationship between the Blaney-Criddle method and the P. E. Index method, data for Mesa, Ariz., for 1945-1946, were analyzed.[10] Because the P. E. Index method is based on field conditions over large areas, the estimated overall consumptive use was adjusted to individual crops as shown in Table 5.

In the previous tabulation, the coefficients (k), for several crops at Mesa, were developed from measured consumptive use. The consumptive use estimates derived by the P. E. Index method represent the average requirements over an entire project, including various types of crops, bare lands, etc. The consumptive use for alfalfa was considered to represent that for a crop density of 100%, and the estimates obtained by the P. E. Index method were adjusted by revising the monthly values on a straight percentage basis between the seasonal measured consumptive use for alfalfa and the seasonal total requirement by the P. E. Index method. This indicates that the crop density represented by the P. E. Index method is approximately 56.4% of the total project area, which appears to be reasonable.

Adjusted P. E. Index method consumptive use estimates for several other crops were calculated by assuming that the individual monthly coefficients (k) bore a direct relationship to the consumptive use factor for alfalfa, and applying this adjustment factor to the adjusted P. E. Index consumptive use estimates

7 "An Approach Toward a Rational Classification of Climate," by C. W. Thornthwaite, Geographical Review, Vol. 38, No. 1, 1948.

8 "Natural Evaporation from Open Water, Bare Soil and Grass," by H. L. Penman, Proceedings, Royal Soc., London, 1948, Series A.

9 "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," by Harry F. Blaney and Wayne D. Criddle, U. S. Dept. of Agric., S.C.S.-T.P.-96, 1950.

10 "Monthly Consumptive Use Requirements for Irrigated Crops," by Harry F. Blaney, Proceedings, ASCE, Vol. 85, No. IR 1, March, 1959.

for alfalfa. The resultant monthly and annual consumptive use estimates for the several crops were very near those obtained by the Blaney-Criddle method.

Atmometer Method.[11]—Black and white atmometers give a measure of the intensity of radiation because the white atmometers reflect more than 90% of the solar energy falling upon them and similar black atmometers absorb more than 50% of the solar energy. Various studies have indicated a high degree of correlation between mean monthly consumptive use of water and mean monthly differences in evaporation between black and white atmometers.

TABLE 6.—MEAN WATER USE BY CROPS IN INCHES PER MONTH AS MEASURED BY SOIL MOISTURE SAMPLING, AND AS CALCULATED BY EMPIRICAL METHODS, AT DAVIS, CALIF.[a] (DIFFERENT YEARS)

Months	Moisture	Blaney-Criddle	Lowry-Johnson	Thornthwaite	Atmometers	P. E. Index
(a) Sugar Beets						
May	5.2	4.4	4.1	3.2	5.1	5.3
June	5.7	4.9	4.9	4.6	5.5	6.2
July	7.1	5.3	5.5	5.7	7.3	7.1
August	5.8	4.9	5.5	5.2	5.9	6.6
Total	23.8	19.5	20.1	18.7	23.8	25.2
(b) Alfalfa						
May	6.8	5.5	4.3	4.1	7.1	6.4
June	7.9	6.0	4.6	4.8	8.0	7.6
July	8.3	6.5	5.2	5.7	8.2	8.6
August	7.1	5.9	5.2	4.9	7.1	8.1
September	4.3	5.0	4.7	3.9	4.3	5.8
Total	34.4	28.9	24.0	23.4	34.7	36.5
(c) Cotton						
June	7.0	4.4	5.5	4.8	7.6	4.9
July	7.4	4.6	6.1	5.9	7.5	5.6
August	6.0	4.2	6.0	4.6	6.1	5.3
September	5.0	3.8	6.1	4.3	5.1	3.8
Total	25.4	17.0	23.7	19.6	26.3	19.6

[a] All columns except P.E. were taken from Table 3, p. 223, report of Halkias, et al.[11]
P.E. values for Alfalfa were estimated as the P.E. project requirement multiplied by a crop density factor of 1.77.
P.E. values for Sugar Beets were taken as 82% of the estimates for Alfalfa.[2]
P.E. values for Cotton were taken as 65% of the estimates for Alfalfa.[2] Blaney-Criddle tabulation gives misleading results.

From the data obtained from the experiments, coefficients are determined which may be used to calculate water use by the different crops. Table 6 shows the monthly water use by several crops as measured by soil moisture sampling and as calculated by several empirical methods, at Davis, Calif.

The five examples cover a wide range of conditions and geographical locations and indicate that there is an apparent conformity between the results ob-

11 "Determining Water Needs for Crops from Climatic Data," by N. A. Halkias, F. J. Veihmeyer, and A. H. Hendrickson, Hilgardia, Vol. 24, No. 9, December, 1955.

tained by the other methods and the P. E. Index method, with the P. E. Index method having the great advantage of simplicity.

Results obtained by use of the P. E. Index method are well within the accuracy of the basic data and appear to be adequate for use in determining consumptive use of water for project formulation.

Individual Crop Requirements.—Although the P. E. Index method is not intended to be used to compute individual crop requirements, it was checked with several such methods. During the 1955 season consumptive use measurements

TABLE 7.—MEASURED CONSUMPTIVE USE (CU) FOR LADINO CLOVER DURING 1955 AND THE PERCENTAGE DIFFERENCE BETWEEN CU AND ESTIMATES OF CU BASED ON VARIOUS PROCEDURES

Consumptive use period	Measured C. U. total inches	Penman E_o x 0.97	Percentage difference between estimated and measured consumptive use							
			Blaney-Criddle	Blaney-Criddle	Thornthwaite E.T. x 1.72	P. E. Index C.U. x 1.93	Evaporation-atmometer		
							Black bulb	White bulb	Difference Bl. - Wh.
Seasonal	coefficient	0.97	K-1.08	Variable	1.72	1.93	0.00304	0.00396	0.0138
5/23-6/3	2.54	. . .	-11.4	-16.9	-30.0	-18.9	. . .	. . .	. . .
6/3-6/11	3.26	-6.7	-33.7	-17.8	-25.5	-32.5	14.1	. . .	. . .
6/11-6/23	3.24	5.6	- 8.6	3.4	- 6.5	-11.1	- 0.1	. . .	. . .
6/23-7/1	2.02	3.5	- 8.4	- 2.0	-15.8	-10.4	- 5.4	. . .	. . .
7/1-7/13	2.48	5.6	15.7	26.2	14.1	21.8	-13.3	-18.9	10.0
7/13-7/21	2.46	-0.4	-12.2	8.9	6.1	- 0.4	- 5.3	- 3.3	- 7.3
7/21-8/2	3.23	2.2	- 6.8	7.1	4.6	4.6	- 3.7	- 3.1	- 0.3
8/2-8/11	2.35	6.4	- 5.5	6.4	7.2	0.9	8.5	12.3	0.9
8/11-8/20	2.29	3.1	- 8.3	- 2.6	1.3	0.4	0.9	2.2	1.7
8/20-8/31	2.68	-4.5	-11.1	-12.7	- 7.8	0.7	- 2.6	- 0.4	- 5.6
8/31-9/13	2.82	-6.0	4.6	8.2	22.0	0.0	8.1	17.4	-20.6
9/13-10/5	2.95	-12.5	20.7	-11.9	- 3.8	11.9	- 1.0	- 5.1	17.3
10/5-10/28	1.49	7.4	108.7	24.8	43.6	70.5	. . .	. . .	. . .
Average percent of difference (Neglecting Sign)	. . .	5.3	19.7	11.5	14.5	15.3	5.7	7.8	8.0

Based on Table 4, page 13 of reference (10) with P. E. Index Method included.

were made on two $\frac{1}{4}$-acre plots of ladino clover at the Irrigation Experiment station near Prosser, Wash.[12] The consumptive use values obtained were used to check the reliability of various procedures in the prediction of consumptive use of water by crops. Table 7 shows the measured consumptive use for ladino clover during 1955 and the percentage difference between the consumptive use as measured and as computed by various procedures.

[12] "Relation of Consumptive Use to Water and Climate," by W. O. Pruitt, Transactions, ASAE, Vol. 3, No. 1, 1960.

The P. E. Index consumptive use factor was obtained by dividing the measured consumptive use figure of 33.81 in. by the P. E. Index consumptive use figure of 17.48 in. The factor of 1.93 is a crop-cover relationship and compares with the figure of 1.77 used in Table 5 for alfalfa. Although the percentare difference by the P. E. Index method was the next highest average percent-

TABLE 8.—COMPUTATION OF EVAPOTRANSPIRATION (ET) AND CROP-MOISTURE DEFICIT (CMD) - COSHOCTON, OHIO, APRIL, 1955[a,b]

Day	Mean to	Rainfall, in inches	Sumation Sum. ET	Com-puted Sum. ET	Sumation P.E. Index Cons. Use	Crop-moisture Deficit[a]	
						(ET method)	(P.E. Index method)
1	53		0.09	0.10	0.11	0.10	0.11
2	56		0.16	0.22	0.23	0.22	0.23
3	51		0.21	0.32	0.34	0.32	0.34
4	44		0.28	0.39	0.43	0.39	0.43
5	48		0.40	0.48	0.53	0.48	0.53
6	53	0.21	0.50	0.55	0.64	0.34	0.43
7	36	0.04	0.57	0.57	0.71	0.32	0.46
8	43		0.65	0.64	0.80	0.39	0.55
9	52		0.77	0.76	0.90	0.51	0.66
10	59		0.90	0.92	1.04	0.67	0.79
11	59	0.11	1.00	1.02	1.17	0.66	0.81
12	60	0.12	1.09	1.11	1.30	0.63	0.82
13	66	1.19	1.24	1.19	1.45	-0.48	-0.22
14	58	0.43	1.32	1.26	1.58	-0.84	-0.52
15	51	0.01	1.37	1.31	1.68	-0.80	-0.43
16	55		1.51	1.46	1.80	-0.65	-0.31
17	57		1.69	1.63	1.92	-0.48	-0.19
18	60		1.87	1.82	2.05	-0.29	-0.06
19	65	0.49	2.03	1.96	2.20	-0.64	-0.40
20	65	0.07	2.17	2.08	2.35	-0.59	-0.32
21	58	0.14	2.18	2.15	2.48	-0.66	-0.33
22	60	0.07	2.40	2.23	2.61	-0.65	-0.27
23	59		2.51	2.43	2.74	-0.45	-0.14
24	63	0.54	2.66	2.57	2.88	-0.85	-0.54
25	52	0.28	2.69	2.64	2.99	-1.00	-0.71
26	57	0.03	2.73	2.71	3.11	-0.96	-0.62
27	51		2.85	2.85	3.22	-0.82	-0.51
28	53		3.07	3.01	3.33	-0.66	-0.40
29	52		3.31	3.17	3.44	-0.51	-0.29
30	57		3.55	3.35	3.56	-0.32	-0.17

[a] Sumation P.E.-CU is based on 1/30 of April P.E. Index method C.U. per day at each mean daily temperature reading, adjusted to meadow cropping by a factor of 1.50.

[b] ET-CA is Evapotraspiration minus condensation absorption, obtained from weighing lysimeters at Coshocton.

[c] Unit: inches

age difference for the season, the periods July 13 to September 13 were lowest of the group. The P. E. Index method was not intended for use in this manner but this check appears to give further credence to the validity of the method.

Short-Period Use of Water.—A method for the determination of daily and other short period estimates of evapotranspiration from meadow crops using

only mean temperature and rainfall was developed by L. T. Pierce, Weather Bureau state climatologist (Ohio).[13] This method involves daily potential evapotranspiration as obtained by the Thornthwaite method and correlated with lysimeter measurements of evapotranspiration minus condensation adsorption. Factors involve evapotranspiration, potential evapotranspiration, length-of-day correction, crop-stage correction, dryness correction, and "rainy-day" correction. A comparison of the figures obtained by Pierce and those obtained by the P. E. Index method are shown in Table 8.

Table 8 shows[14] a general verification of the results obtainable by the Pierce method and also indicates that the P. E. Index method would give results which appear to be just as good. Although there are fairly large departures on individual days, the apparent errors are generally selfcompensating. Insofar as practical application of the P. E. Index method to this type of use is concerned, it is readily apparent that individual daily differences are not important as water will not be applied to each acre on a daily basis and the monthly demand difference is insignificant.

CONCLUSIONS

A method is described whereby monthly and annual consumptive use estimates may be determined for project formulation utilizing only the average monthly temperatures and a set of predetermined P. E. ratios. Results obtained by the P. E. Index method were compared with those obtained by many other methods over a wide geographical range and a great divergence in cropping procedures as well as different crops. It is believed that the validity of the P. E. Index method has been shown to be comparable to that of any other method and has the advantage of its extreme simplicity.

Although the P. E. Index method was not intended for use with individual crops or for very short periods of time, the results shown in this paper indicate that it may have possible use as a rapid check of the more involved methods used for these purposes.

ADDITIONAL REFERENCE

1. "Sprinkler Irrigation," Sprinkler Irrigation Assoc., 1955, Table IV-1, p. 83.

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13 "A Practical Method of Determining Evapotranspiration from Temperature and Rainfall," by L. T. Pierce, Transactions, ASAE, Vol. 3, No. 1, 1960.

14 Ibid., Table 1, p. 80.

Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

IRRIGATION SYSTEMS OF THE TIGRIS AND EUPHRATES VALLEYS

By Stanley S. Butler,[1] M. ASCE

SYNOPSIS

The high potential for irrigation, and the fluctuations in the status of actual development during the sixty centuries of irrigation in the Tigris and Euphrates Valleys of Iraq are described herein. Great progress has been made since 1951, when an increase in income from oil production made it possible to accelerate the design and construction of dams, canals, and deep wells, and to start a drainage program. The United States participated through its engineers and construction firms.

INTRODUCTION

During the sixteen-month period from November, 1953, to March, 1955, the writer was employed as an engineering hydrologist in Iraq, and made trips to various parts of that country.

In the United States, many improved ideas for irrigation and irrigation engineering have been developed over the past century. However, it might be worth while to look at a region which has experienced, not merely one century, but sixty or more centuries of irrigation. Perhaps in these sixty centuries there may be lessons not easily seen in the experience of one century.

As shown in Figs. 1 and 2, Iraq (formerly called Mesopotamia) includes nearly all of the irrigable land between and bordering the Tigris and Euphrates Rivers (Syria has the remaining portion). Irrigation is essential, as the climate of the agricultural region is arid in the southern and central parts

Note.—Discussion open until May 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 4, December, 1960.

[a] Presented at the October 1959 ASCE Convention in Washington, D. C.

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FIG. 1.—HYDROLOGY OF THE TIGRIS-EUPHRATES DRAINAGE BASIN

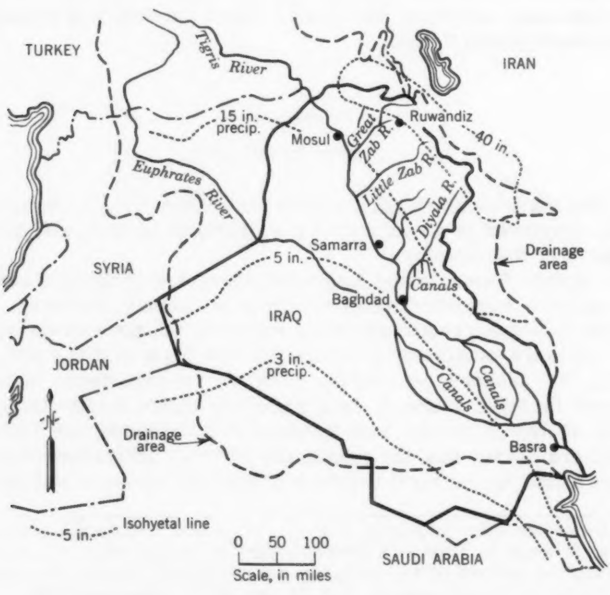

FIG. 2.—IRRIGATION IN IRAQ

(at Baghdad the mean annual rainfall is 5.3 in. and the mean annual temperature is 73°F), and semi-arid in most of the north. The only exceptions are the high mountain valleys in the far north. For example, as indicated in Fig. 1, the town of Ruwandiz, 30 mi south of the Turkish border, receives an average of 37 in. some of which is in the form of snow. More than half of the annual precipitation occurs during the three winter months, and less than 10% falls during the six months centering on July. In summary, it might be said that the climate of Iraq is closely similar to that of the inland valleys and mountains of California, except that for the same elevations, the temperature in Iraq is about 10°F warmer.

It was nearly 12,000 yr ago that man first began the harvesting of crops, giving up the roving life of the hunter and the nomad to some extent. It is believed that this change may have occurred first in the Middle East, perhaps in northern Mesopotamia. From that time on, Mesopotamia maintained a position in the forefront of civilization, until, 700 yr ago, Mongols from central Asia overran the country and reduced it to a land of bare subsistence living, from which it is now emerging. To Americans, 700 yr of ignorance and poverty seems a long time, but it should be noted that 700 yr is about 6% of the 12,000 yr that constitute the period of agricultural development. In other words, Mesopotamia was one of the leaders of the civilized world during the first 94% of the period, and only in the last 6% of the period have other regions surpassed it.

Throughout its long history, Mesopotamia's prosperity and cultural advancement have been closely related to the status of its irrigation development. When the irrigation systems were in a high state of development and operation, the population was large (three or four times the present population), powerful, and prosperous, and wealth was available for the arts, and, later, the sciences. When wars or neglect allowed the irrigation systems to decline, the prosperity and the civilization declined too. Through the centuries, Mesopotamia experienced numerous fluctuations in the strength of its civilization, and the story is not yet finished. Perhaps, when the present 12,000-yr agricultural history has grown to 15,000 yr, the recent 700-yr low period will be seen as an unimportant temporary dip in the long-range fortunes of the region.

IRRIGATION POTENTIAL

The various Mesopotamian dwellers of the past, the Sumerians of 5,000 yr ago, the Babylonians of 3,000 yr ago, the Arabs of 1,000 yr ago, and the Iraqis of today, have all had at their disposal about the same natural advantages for the development of irrigation. Probably, the climate has not changed much during that time. The major changes in the land have been the gradual filling in of the swamps of the delta of the Tigris and Euphrates Rivers, along with some general subsidence and some local folding.

The valley of the Tigris and Euphrates Rivers is a geosyncline formed many thousands of years ago. It is believed by many (but not all) investigators of the subject that 10,000 yr ago the Persian Gulf extended about 350 or 400 mi inland from its present position, and the gulf was gradually filled with sediments during that time.

As it was thousands of years ago, the land is potentially fertile and productive. When properly irrigated and maintained, the land is good, and will

grow a wide variety of crops in great abundance. The rivers provide a dependable flow of water of good quality, readily available to the land even as they did thousands of years ago. Also, as the situation existed thousands of years ago, the parts to the Mesopotamian valley not served by water from the rivers have no change of developing irrigation for more than a few gardens, because the low mean annual rainfall and the hot climate (sometimes exceeding 120°F) allow very little influent seepage for well water, and the surface channels ("wadies") are dry except after rain storms. In addition, the wells, especially the shallow ones, often yield water of poor quality.

There is another matter that also has not changed since ancient times, and that is the necessity for good planning and administration. Now, as then, successful development of irrigation in the valley of the Tigris and Euphrates is greatly dependent on good engineering, progressive laws, efficient administration, and a condition of peace and cooperation with neighboring countries.

THE RIVERS

Only Egypt is as dependent on a river system as Iraq. In addition to almost complete dependence on the rivers for an irrigated agriculture that employs about two-thirds of the population. Iraq also uses the rivers for navigation and for fishing, and, some day in the future, will use them to supply a part of her electric power.

The rivers have their beginnings in the high mountains of Kurdistan, in eastern Turkey. Eventually they join, and flow the final 100 mi as a single river, called the Shatt-al-Arab, to the Persian Gulf. The Eurphrates River is the longer, but the Tigris has the greater mean annual discharge (45,000 cfs at Baghdad, compared with 30,000 cfs for the Euphrates), and the greater value for the minimum recorded annual mean discharge (18,000 cfs as compared with 13,500 cfs). Also, the Tigris River has the greater tendency to flood, having achieved a peak (March, 1954) in the order of 500,000 cfs as compared with about 200,000 cfs for the Euphrates.

Two types of floods occur, those caused by winter rain, and those caused by winter and spring snowmelt in the mountains of Turkey and Iran. Usually, the main flood peaks occur with the melting of the snow in April or May, with the Tigris peak occurring earlier than the Euphrates peak by several weeks. In some years, however, heavy rains result in major winter floods, as for example in March, 1954, when one of the greatest floods of record occurred, killing 50 people and causing damage estimated at $200,000,000.

Although the annual discharge of the two rivers is quite large, it is the low flow which is the critical matter from the standpoint of irrigation. The ancients had no significant provisions for storing water within a given season, much less storing it for a carry-over from one season to the next. For a time there was a high dike or wall across the valley at Babylon, built for military purposes, but also used to store flood water for irrigation.) Thus, when the natural climatic fluctuations brought on a relatively dry year, the irrigation-supported economy suffered. This situation still holds true. Fortunately, the quality of the river water is good, even during low water periods. Much of the land is alkaline or saline, but this is caused by inadequate drainage, not by the use of river water of poor quality.

In the lower delta region the tides back up the water, causing it to overflow the banks or flow into ditches for irrigation. Further upstream, where the

tides do not provide this service, another condtion exists that is both a help and a danger. For a distance extending about 300 or 400 mi upstream from the Persian Gulf, the river sedimentation process has produced natural levees on the banks of the rivers, and the river water levels tend to be higher than the bordering agricultural land. This has made it possible, for thousands of years, to divert water to the land by gravity (throughout the year in the lower reaches, and during the annual high water periods in the upper reaches of the 300 or 400 mi). But this condition has also resulted in a serious drainage problem and a serious flood problem. Still farther upstream, the water of the rivers is quite substantially below the elevation of the adjoining land, so that no flood hazard exists, and also no opportunity exists for gravity flow of the water to the land except by the construction of diversion dams.

POTENTIAL WATER SUPPLY FOR IRRIGATION

In the preceding section, some of the natural characteristics of the two rivers are noted, among them the fact that the natural run-of-water yield of the rivers is inadequate because of low discharge in the summer and fall seasons when it is most needed. In addition, taking too much water from the rivers hurts fishing and navigation.

Thus, it becomes desirable to increase the summer and fall water supply, especially for the years of lower than normal discharge. Two methods that offer promise are building dams for the storage of water, and using ground water for irrigation. Both of these methods are being explored, but much the greater emphasis has been given to the construction of dams. Among the reasons for this emphases are the existence of the huge undeveloped potential water supply of the rivers, the need for large numbers of competent maintenance technicians to operate ground water irrigation schemes, the relatively poor quality of the ground water as compared with river water, the auxilliary flood control benefits derived from the dams, and the incidental aid to fishing and navigation resulting from the operation of the dams for irrigation. There is also a possibility that some time in the future it will be economically feasible to use the flow through the dams as a major source of power; however, the general prospect (as of 1960) is that power from locally produced gas and oil will prove more economical.

It is considered by the planners that if neighboring countries will allow dams and reservoirs to be built in the upper reaches of the rivers, and if Iraq can plan on the basis of sole user of the irrigation water supply from the two rivers upstream from the Shatt-al-Arab, it will be economically feasible to develop an irrigation water supply from the two rivers to irrigate about 1.5 times the presently irrigated area, and to irrigate most of it at about two to three times the present intensity of irrigation (by having more crops per year, and by rotating crops instead of allowing half of the land to lie fallow). Thus, the total extent of irrigation, expressed in units of "crops per year" times "area," could be expanded by a factor of about 3.5 or more. This factor doubles to 7.0 when allowance is made for the doubling of the crop yield, which might be achieved by providing drainage, using more fertilizer, and applying the irrigation water with greater care. This is on the basis of river supply, without any allowance for possible additional supply from ground-water development.

It should be noted that these determinations assume (1) that Iraq's neighbors will cooperate in the building and operation of dams and reservoirs in the upper parts of the rivers and their tributaries, and (2) that no other country will extract, for consumptive use, any appreciable portion of the river water.

There are a number of reasonably good dam sites on the two rivers and their tributaries in Iraq, as shown in Fig. 2, and there is some possibility that the Tharthar and Abu Dibbis depressions may be of some use as irrigation storage reservoirs despite their existing saline condition and their high evaporation potential. In addition, it may be possible to build some dams in the upper reaches in Turkey. In the case of the Euphrates, however, it is not only the Turks whose cooperation would be required. In addition, the Syrians have a stake in the Euphrates, which passes through Syria for a distance of nearly 400 mi enroute from Turkey to Iraq. The United Arab Republic, of which Syria is a part, is making plans for a dam-and-reservoir project on the Euphrates River, to impound 1.5 million acre-ft of water for irrigation. Such a project would significantly reduce the potential water supply available to Iraq. Syria also has access to the Tigris River, for a distance of about 18 mi, but it is considered unlikely that Syria will find it feasible to divert any appreciable amount of water along this reach.

Of Iraq's four neighboring countries, only Syria is likely to draw upon either of the two rivers to a significant degree. Turkey may want to develop power from the rivers some day, but she has no need to develop much of the water for irrigation, as the regions of the two rivers in Turkey are humid or semi-humid, and are too mountainous to provide much land for agriculture. Saudi Arabia, bordering Iraq on the southwest, can draw on the rivers only by permission of Iraq and through a long pipe line. The fourth neighbor, Iran, has an interest in the Tigris basin, sincemmany of the tributaries of the Tigris have their upper reaches in Iran. However, in the case of the tributaries of importance to Iraq's plans, the portions of the drainage areas in Iran are generally small, and so mountainous that Iran will not have much use for the water.

Although the Iraqis need not fear that the Iranians will extract any appreciable percentage of the volume of runoff of that part of the Tigris River system of interest to Iraq, it is still true that, in several areas bordering Iran, there is often a severe shortage of surface water for irrigation in Iraq. The areas in question receive water from small streams which pour out of the mountains along the Iranian border. In wet years there is no problem, but in dry years the Iranians are in a position to take nearly all of the water of these low-yield streams if they choose to do so. Possibly it might be feasible to construct a number of small dams on these small streams in Iran to supply the needs of both the Iranians and the Iraqis during the dry years, if the Iraqis could count on international cooperation. It may be that this is a chance worth taking.

However, there is another source for irrigation water supply along the Iranian border that is being developed, and that is the ground water. The Iranians might cause a shortage of surface water, but a ground-water supply developed on the Iraqi side of the border is less subject to possible tampering by the Iranians. Fortunately, in this border region, the ground water is of reasonably good quality (as compared with rather poor ground water in much

of the rest of Iraq), and the permeability of the aquifers in this region is fairly high.

POTENTIAL GROUND-WATER SUPPLY

From Iraq's standpoint, it is unfortunate that her international borders do not follow along the natural topographic drainage divides separating the Tigris-Euphrates drainage area from other drainage areas, for then Iraq, as sole custodian of the two rivers, would be in an exceedingly fine position to make maximum use of the huge area of potentially productive agricultural land of the Mesopotamian valley. As things stand, Iraq has the valley, but Turkey, Syria, and Iran control the upper half of the combined drainage area of the two rivers, where nearly all of the runoff originates, as shown in Fig. 1. This dependence on international cooperation makes it desirable for Iraq to consider all possible ways to develop a water supply, rather than rely exclusively on direct diversion from the two rivers. This is a primary reason for developing ground water, but it is not the only reason. Additional considerations favoring development of ground water are (1) the fact that in some cases, pumping from the ground water adjoining the rivers may be less costly than building structures to raise the water level for gravity diversion, (2) the fact that part of the cost of pumping ground water for reuse can be written off as expenditure for necessary drainage, and (3) the fact that many large regions are too far or too high to be able to draw on river flow at all, and must depend on ground water recharged from local rainfall. Each of these three considerations will be examined in turn.

It was previously noted that for a distance of about 300 or 400 mi upstream from the Persian Gulf, the water levels of the rivers tend to be higher than the adjoining agricultural land, but farther upstream, the water levels are generally lower than the adjoining land and gravity flow can be achieved only by building diversion dams ("barrages") to raise the level of the water. Most of this upper valley land, being too high to receive water by simple gravity during the past thousands of years, is relatively free from the alkali and salts which are found in the lower parts of the valley. Much of it is good land with good natural drainage, and needs only an irrigation water supply to make it productive.

Preliminary surveys and tests indicate that the aquifers underlying much of this land are sufficiently permeable to allow a considerable quantity of water to seep into them from the rivers, if it should be decided to pump them extensively, and so induce hydraulic gradients inland from the rivers. The distance inland to which this pumping-supported irrigation development could be extended would be limited, of course, by the greater pumping heads encountered farther inland. Consequently, the Iraqis would probably reach uneconomically high pumping heads after penetrating inland farther than about five or ten miles with such an irrigation development. In one particular location, the ground water is receiving artificial replenishment as an incidental benefit associated with a flood control project.

At Samarra, about 90 mi upstream along the Tigris from Baghdad, a diversion dam called the Tharthar Barrage was completed in 1956. Its purpose is to divert flood water to a below-sea-level depression about 40 mi southwest from Samarra, thus clipping the peaks from the major floods which, in the

past, have endangered Baghdad and the lower valley areas. The Tharthar Barrage, though constructed for flood control, provides a ready-made opportunity to divert excess discharge to the adjoining land where it can be allowed to seep to the water table and recharge the ground water along the route of the 42-mi-long diversion channel leading to the great inland depression.

It is a well recognized principle that where stream discharge is diverted for irrigation, the irrigation development should be accompanied by plans for any drainage that may be required to keep the ground water elevation from rising to the point where it interferes with the fertility of the land. In some cases, the characteristics of the underlying strata and the adjoining channels provide natural drainage; otherwise, it should be provided artificially. If the drainage is accomplished by means of tile lines or open ditches, the water is wasted unless it can be reused from the ditches downstream.

This may be the best solution if the water supply is plentiful and the underlying strata are suitable for ditch or tile drainage. However, considering Iraq's great amount of irrigable land, and the limited water supply independent of foreign control, it has been proposed that the irrigation deep seepage be pumped to the surface and reused, insofar as is feasible. This operation would be limited, of course, by the necessity for avoiding the accumulation of high concentrations of salts in the ground-water body, and thus some of the pumped water would have to be wasted out of the area.

In the great valley area between the two rivers, plus the area along the banks west of the Euphrates and east of the Tigris for some distance, plus along the Iranian border, where a number of small streams enter Iraq from the Iranian mountains, water is available by surface diversion. However, there are areas other than those described previously, including some of the upper areas of the Mesopotamian valley, plus a large desert area west of the Euphrates River, which have no chance, now or in the future, to develop a surface water supply. The aquifers in these areas, too high in elevation or too far from the rivers, must rely for recharge on local rainfall (except for the possibility of supplies of deep artesian water in a few areas). As discussed elsewhere,[2] in areas such as these, with high temperature and low annual rainfall, evapotranspiration consumes so much of the local rainfall that the safe yield for irrigation ranges from very small (in the semi-arid areas) down to almost zero (in the arid areas).

IRRIGATION IN ANCIENT TIMES

The large-scale diversion of water by man may have had its beginnings in ancient Mesopotamia 5,000 or 6,000 yr ago. Egypt also developed an ancient irrigated agriculture, but in Egypt, irrigation occurred each summer by the natural flooding of the land along the banks of the Nile, followed (except in the delta region) by a good natural drainage, leaving the land ready for planting in October or November. The ancient Mesopotamians did not have these advantages. Tigris and Euphrates flood peaks occurred in April or May, too early to wet the land for fall planting (the summers are too hot), and the Mesopotamian valley lacked good natural drainage. The Mesopotamian valley experienced many floods, but they were not the gentle floods of the Nile in which water gradually rises over the banks, soaks the land and then recedes. Instead, the

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[2] "Engineering Hydrology," by S. Butler, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1957, Figs. 10-19, pp. 237-38.

Mesopotamian valley, between the two rivers, and also for a distance on the sides of the rivers away from the valley, was regularly subjected to floods of damaging proportions, and sometimes of disasterous proportions. During the periods between floods, the people could till the land, but it took some engineering skill to do it, because instead of receiving a natural annual irrigation as in Egypt, the ancient Mesopotamians had to divert the water from the rivers by means of canals.

Although Nature did not provide as ideal a situation for the ancient Mesopotamians as was provided for the Egyptians, still they had a near-ideal situation for the beginning of a canal irrigated agriculture. The land was fertile, the river water was of good quality, and the river elevation was often higher than the elevation of the land surface, so that a simple cut in the natural dikes, which constituted the banks of the river, brought water flowing to the land. Furthermore, Nature provided an additional advantage in the form of physiographic conditions such that one river tended to be lower than the other. Also, the Tigris flood peaked and receded earlier than the Euphrates, so that during the critical summer and fall months, its water surface was somewhat lower than that of the Euphrates, which paralleled it about 20 mi to 100 mi to the southwest. For these reasons, the ancient Mesopotamians could take water from one of the two rivers (usually the Euphrates) into their canals, and discharge the excess water into the other (usually the Tigris) at a lower elevation. To increase the canal slope, it was the practice to lay out the canals along a diagonal route, so that a canal discharged at a point downstream from a point directly lateral from the intake on the other river.

Sedimentation was a problem requiring constant attention. During periods of stability and efficient administration, this attention could be given, but at other times, the irrigation works became badly silted. In many cases, the canals were so prone to sedimentation that it was considered easier to abandon them when they became silted, and build new ones.

During a period of about 4,000 yr, from about 2,500 B.C. to the 13th or 14th century A.D., Mesopotamia was famed for its irrigated agriculture. By modern standards crop production was no doubt low, and getting lower toward the end of the period because of decreased fertility, but the skill of the people and the great amount of well-watered land in this sunny climate nevertheless made Mesopotamia prosperous. To allow the land to drain and to combat the gradual loss of fertility, it became the custom to irrigate only half of the land during a given year, letting half lie fallow on alternate years. The ancients did not discover the advantages of crop rotation, but there are indications that they were aware of the beneficial effects of some types of crops over others in maintaining fertility. They irrigated the land by flooding it, first dividing it into basins separated by low dikes, and letting the canal water into each basin in turn.

In addition to their skill with irrigation canals, the dwellers of the land between the two rivers showed ingenuity in other aspects of water development, including the wondrous Hanging Gardens of Babylon, and the more practical water tunnels, horse or donkey-powered chain lifts, and at least one major irrigation diversion dam.

Babylon, which ruled as a city-state from about 2,200 B.C. to 539 B.C., was located about 50 mi southwest from modern Baghdad. Here, Nebuchadnezzar had his Hanging Gardens, which were listed by the ancient Greeks as one of the "Seven Wonders of the World." Although there is no detailed description of the gardens, it is thought that they were a series of terraces more than 100

ft in height, adjoining the imperial palace. How the irrigation water was raised from the Euphrates River to the higher elevation is not known. Perhaps they used a series of wooden bucket wheels or chain-bucket lifts similar to those still used in Iraq.

The ancient Mesopotamians had various water-lifting methods, but it is the chain-bucket lift or "na'ur" that is best known. Buckets of wood are attached to an endless chain which is propelled by a wooden sprocket. The chain of buckets travels an oval route from the land surface down to the water table and back to the land surface, bringing each time, a small quantity of water, which is spilled into a trough at the land surface, and flows from there to the irrigation field. The device was powered by slaves or by a horse or a donkey. Judging by the examples now in use (Fig. 3), they were probably capable of raising water as much as 50 ft or more, and commonly produced a discharge of about 10 or 15 gpm.

Another ancient method of water development is the kahriz (called the "khanat" in Iran), a mildly sloping tunnel which for thousands of years supplied hundreds of Mesopotamian villages with water for domestic use and for irrigation. As illustrated in Fig. 4, these tunnels are still in use today to some extent, not only in Iraq, but throughout the Middle East. In ancient times, the art of constructing the kahriz was highly developed, having been introduced into Mesopotamia by the Persians. In recent decades, the few attempts to repair old ones or construct new ones have in general been unsuccessful. To construct a kahriz, the ancients first looked for a place where the ground water level was near the land surface, and could be relied on to remain at that high level with a good recharge source. Usually such a site was found near a perennial surface stream, or at the base of a line of hills where the rainfall was greater than elsewhere, and where bedrock or shallow strata prevented the water from sinking too deep. At such a site, the builders developed the intake, sometimes with two or three branches, and then started the tunnel. Some were lined, some half lined, some not lined at all. They were made barely large enough for boys or small men to work in them while constructing and repairing them. In length they ranged from only a few hundred yards to many miles, with vertical access holes spaced about 20 yds. a part. The discharge varied from only a few gallons per minute in some cases, up to many hundreds of gallons per minute in the larger ones.

There are several instances of the building of dams by the ancient Mesopotamians. Historians say the Babylonians once built a dam to divert the flow of the Euphrates so that they could lay the stone piers for a bridge.

A striking example of an ancient diversion dam is the Nimrud Dam, which was built across the Tigris at a point about 20 mi upstream from Samarra, and about 110 mi upstream from Baghdad, as shown in Fig. 2. Here, water from the Tigris was diverted through the huge Nahrawan Canal, to irrigate a desert area extending 65 mi to the present town of Baquba, 30 mi northeast of Baghdad. At Baquba, the Nahrawan Canal joined with the Diyala River and supplemented its discharge for the 120-mi reach of the Diyala in its ancient course from Baquba to the Tigris River at the present town of Kut. Thus, thousands of years ago (possibly as early as 2500 B.C.), the ancients constructed a successful dam across a river of 45,000 cfs mean annual discharge, and of peak discharge 500,000 cfs or more in some years, not only irrigating a desert area 65 mi long, but also transferring water from one river to another and supplementing the supply there for an additional distance of 120 mi. The

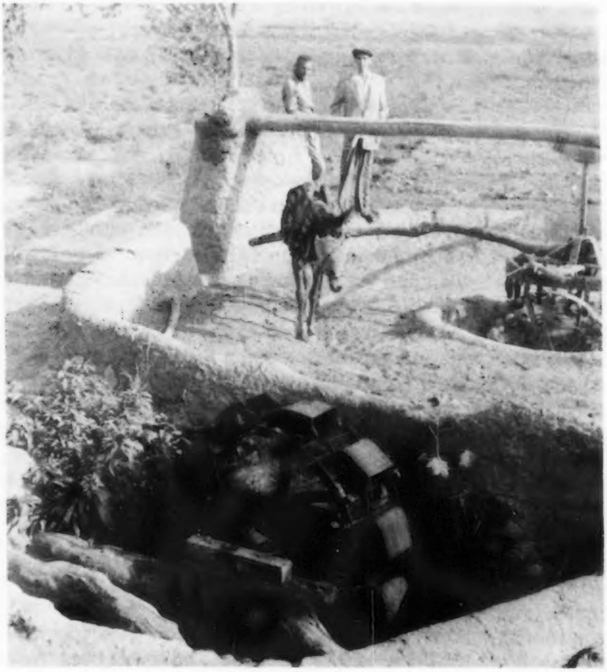

FIG. 3.—DONKEY-POWERED CHAIN-BUCKET WATER LIFT, WITH IRRIGATED FIELD IN BACKGROUND, NEAR ERBIL, IN NORTHERN IRAQ

FIG. 4.—OUTLET FROM A FIVE-MILE-LONG WATER-SUPPLY TUNNEL OR "KAHRIZ," NEAR SINJAR, IN NORTHERN IRAQ

dam is thought to have been destroyed by a flood in 629 A.D., shortly before the Arabs took over Iraq from the Persians. The Caliph Mutawakkil, grandson of the famous Harun al-Rashid, attempted to rebuild the dam in the 9th century A.D., but without success.

IRRIGATION IN MODERN TIMES

The Iraq of today applies irrigation principles and methods which range from the most primitive to the most modern. The government of Iraq has taken special pains to encourage the thousands of young men who have gone abroad for an education to study engineering, especially irrigation engineering, and a fair portion of them have done so, attending prominent engineering schools throughout the world, especially those in Europe, Turkey, Egypt, and the United States. However, when these men returned to Iraq to apply the methods they learned and observed abroad, they found a difficult situation. They found low salaries, and uneducated population (about 15% of the people can read and write, and most of these are in the major cities), widespread superstition, and firmly established ways of doing things. Despite these difficulties, important progress is being made. Salaries are rising, and the people are being educated. As they become educated, the Iraqis are developing an intense desire to do things better and to raise their standard of living.

The old methods remain to a considerable extent, but they are becoming less common, and many of the Iraqis who use the old methods are aware that there are better methods. Where they continue with the old methods they often do so because the old equipment is there and might as well be used until they can afford something better. They continue to winnow grain by throwing it in the air until they can afford threshing machines; they continue to irrigate by flooding until somebody teaches them how to furrow-irrigate or to use sprinklers; they continue to regulate the flow into farm laterals by means of compacted clay weirs loosely filled with dirt when not in use, until modern weir gates can be introduced; and where they continue to use the horse-drawn "na'urs" they do so only until they can afford to install centrifugal pumps.

Of course, there is a difference between a general widespread realization that better methods exist, and the knowledge and ability to perform with the better methods and equipment. Much education, not only of the formal kind, but also in the techniques of irrigation must be done, and this will take much time even though the people are becoming more receptive to change. This is expecially true when it comes to the use of machinery and the measurement of water. An American who has been acquainted with tools and mechanical equipment from childhood may find it hard to visualize the difficulty of the illiterate Iraqi farmer who, at 30 or 40 yr of age, is first introduced to mechanical equipment quickly, but is slow to appreciate the importance of the care and maintenance of the equipment.

Then there is the matter of water rights and the measurement of water. Until recently, if one farmer was supposed to have two times the water of his neighbor, he was allowed to have two times the area of opening from the canal, usually estimated by eye. No particular attention was given to whether be made the opening wide or deep. However, there was usually a visual inspection of the diversion flow by a government representative to see if it looked all right. The farm lateral has commonly consisted of a broad, rounded, compacted clay weir loosely filled with earth when not in use, its size established according to the water rights of the diversion. These rights, based on centruies-old

Arabic common law, and administered by the Iraq Irrigation Department, are in terms of a weir flow of a given size operated for a certain number of hours on specified days. The farmer cannot divert at other times except by exchange agreement with his neighbors.

The Iraqis are trying to learn in a few decades what the Americans and Europeans learned gradually through many decades. Among the educated Iraqi engineers and agriculturists of today, there are plans for introducing modern methods and techniques as rapidly as possible, including the doing away with the old system of letting half of the irrigation land lie fallow, and the restoring and maintaining of fertility by better drainage, the use of fertilizers, and the rotation of crops.

In 1910, the visitor to Iraq, at that time a province of the Turkish Ottoman Empire, found irrigation practice little different from that of past centuries. In general, the methods were those of a thousand years ago, and the land was in worse condition than that of a thousand years ago from the standpoint of fertility and sedimentation of the canals. In 1910, Baghdad had about 50,000 people and Iraq had a total of about three million persons. Turkey had started to show greater interest in Iraq toward the end of the 19th century, and some progress had been made. However, the real change from the Middle Ages to modern times started when the British gained control of the country under a League of Nations mandate at the end of World War I. The big spurt started in 1951, when neighboring Iran's political troubles suddenly increased the world demand for Iraqi oil. This demand has kept up, and Iraq's share of the oil revenue is currently in excess of 200 million dollars per year.

At the present stage of progress, Iraq is far behind the United States, but far ahead of the Iraq of the year 1910. Since 1910, the area under irrigation has increased many fold. In 1910 there were probably no more than a few dozen irrigation pumps in Iraq; several thousand centrifugal pumps now line the Tigris River upstream from Baghdad. These pumps are operated more or less continuously, each discharging an average of several hundred gallons per minute into an irrigation ditch that is often lined with concrete for the first 25 or 50 ft. They pump directly from the river or from 3 ft to 10 ft diameter hand-dug wells bordering the river. Near the rivers, hand-dug wells work fairly well, but away from the rivers, farmers have trouble with fluctuating water tables, and sometimes have to stop pumping when the water level falls below the intake to the pump. Here the shallow hand-dug wells are being replaced, as fast as money and men are available, by deep wells and modern turbine pumps. Until 1953 there was not a single turbine deep-well pump in operation in Iraq. Now, seven years later, there are several hundred, a few in the arid eastern and western deserts, but most of them in the northern and eastern semi-arid regions.

This leads to the subject of ground-water safe yield, that is the rate of extraction for consumptive use that can be maintained more or less indefinately. In semi-arid and arid regions it is not economically feasible to determine the safe yield in advance of development with anything but a very rough degree of accuracy. What can be done is bracket in a reasonable range of values within which the safe yield may be expected to lie. Although rough, such an analysis can serve as a guide in holding a reign on over-optimism that may otherwise influence the planners. It is almost universally true that the nonspecialist in ground water tends to greatly overestimate the safe yield of semi-arid and arid regions. Backed by geohydrologic studies, the administration in Iraq is aware of this danger and has sufficient data to defend its policies in avoiding overdevelopment of the ground-water basins.

There are three classes of ground-water development areas in Iraq. First, there are those areas that adjoin the two main rivers or their tributaries and can draw water which is recharged by influent seepage from the rivers. Such areas can safely pump all they want without endangering the river supply. Secondly, there are the semi-arid rolling plains and hill country in northern Iraq, where historically, there has been only dry farming plus a few shallow wells in the hollows, plus the collection of rain water, immediately after storms, behind small earthen dikes. Now, with modern deep wells, it is possible to achieve full development of the limited ground-water potential.

Thirdly, there are those arid areas, both east and west of the between-the-rivers area, but especially west of the Euphrates River, in which the climate is hot, the mean annual rainfall is low (3 to 8 in per yr), and there is no possibility of large agricultural development. Here, the nomadic Bedouins reign, with only nominal control from Baghdad, with their broad tents and their herds of camels, sheep, and goats. Throughout untold thousands of years, nomads have lived here with little change in customs, although now they are somewhat influenced by the 20th century changes that are affecting the rest of Iraq so greatly. The camel is being replaced by the Jeep (American and British) as the accepted mode of desert transportation, television antennas may soon rise from the tops of Bedouin tents, and the last decade has brought the Bedouins a few deep wells to supplement their traditional supply from springs and from shallow wells in the hollows and dry washes.

Although in the regions away from the rivers the ground-water safe yield ranges from small down to almost zero, this yield is nevertheless important in providing water for livestock and for small gardens, so that farmers and villagers in the dry-farming areas, and Bedonuins in the deserts, can have vegetables with their roast lamb.

The major dams and barrages in existance, or proposed, are shown in Fig. 2.

Dokan Dam.—This is a concrete arch dam which will store water of the Lille Zab River for irrigation and flood control, and also power at a later date. Scheduled for completion in 1960, it will cost $33,000,000. Its essential features are: storage 4,600,000 acre-ft; height 385 ft; and length 1,200 ft. It is expected to provide irrigation water for 800,000 acres. It was designed by the British and built by the French.

Derbend-i-Khan Dam.—This is a rock-fill dam that will store water of the Diyala River for irrigation and flood control, and also power (a small power plant now, more later as needed). Scheduled for completion about 1960, it will cost $46,000,000. Its essential features are: storage 2,500,000 acre-ft; height 440 ft; and length 1,500 ft. It is expected to provide irrigation for 900,000 acres. It was designed and built by United States firms.

Tharthar Barrage.—This is a concrete diversion dam that diverts flood water from the Tigris River at Samarra, 90 mi upstream from Baghdad, passing up to 320,000 cfs through a large 42-mi canal to a below-sea-level depression where evaporation disposes of the water. Also diverts water for irrigation. It was completed in 1956 at a cost of $26,000,000 for the barrage, and $18,000,000 for the canal. The barrage length is 840 ft. It was designed by the British and built by British and German contractors.

Ramadi Barrage.—This is a concrete diversion dam that diverts up to 100,000 cfs of flood water from the Euphrates River through an inlet control structure called a "regulator" (Fig. 5), about 70 mi west of Baghdad, to nearby Lake Habbaniyah, a natural depression that has been made more useful by

constructing a 5 ft dike around it. From Lake Habbaniyah, some of the flood water can be fed back to the Euphrates River at a point downstream to help maintain summer discharge, or it can be discharged southward to the Abu Dibbis Depression where it will evaporate. It was completed in 1956 at a cost of $4,000,000 (for the barrage only; total cost of the project including channels, control works, and dikes, $40,000,000). Its length is 700 ft. Designed by the British, it was built by the French.

Kut Barrage.—This is a diversion dam that diverts water from the Tigris River downstream from Baghdad, supplying irrigation water to more than a million acres. It was completed in 1939, built and designed by the British Its length is 1,600 ft.

Hindiya Barrage.—This is a diversion dam that diverts water from the Euphrates River, supplying irrigation water to about 1.5 million acres. It was completed in 1913 at a cost of $600,000. Its length is 800 ft. under Turkish administration, it was built and designed by the British.

Under consideration for possible future construction are five additional dams, one on the Great Zab River (engineered by an American firm), two on the Tigris River near Turkey, and two on the Euphrates River near Syria.

Plans have been made for the construction of many new canals as more irrigation water becomes available. Much more attention to sedimentation works at the inlets to canals is in the plans. This, along with the ambitious new program of forestry and soil conservation that is in progress, should greatly relieve the sedimentation problem. The new systems of canals will be more orderly than the haphazard systems of the recent past, but not as orderly and simple in design as the ancient system. The reason for this is that the ancient irrigation water source was mainly the Euphrates River (this is true today also), from which the water was diverted through a system of canals to the Tigris River at a lower elevation. The system for the future will probably use more water from the Tigris than from the Euphrates.

THE DRAINAGE PROBLEM

Where irrigation is easy, drainage is difficult, and where drainage is naturally good, irrigation is difficult. That is the historical basis for Iraq's present situation in regard to saline and alkaline soils throughout the Mesopotamian valley. Nature, in providing a condition whereby water could be diverted to the land for irrigation so easily, invited the type of operation that led to poor drainage and, inevitably, to soil problems. Until the last few years (since about 1953), the only reaction of the farmers, as the soil became water logged, was to let the land lie fallow on alternate years, and eventually abandon the land and move to other sites. Gradually nearly all of the lowlands became saline or alkaline, and then the farmers were forced to put the less easily irrigated lands into production, by means of longer canals, water lifting devices, and diversion dams. These newer lands, by virtue of their higher elevation relative to the rivers, had better natural drainage. Also, they were brought into production more recently than the lower areas, and so they are now in better condition. Thus, in the lower parts of the valley the saline and alkaline condition is quite bad, in the middle portions it is moderately bad, and in the upper portions of the valley the condition varies from fair to good. Then, farther upstream, past the areas of regular long-time irrigation, very little saline or alkaline soil is found.

Fortunately, most of the salts present are readily soluble calcium salts, and can be leached without difficulty once the drainage system has been provided and the leaching program set up. Only in a relatively small portion of the valley, mostly toward the Persian Gulf, is there much of the "black alkali" condition, that is much more difficult to overcome.

Tests have shown that in general, throughout the valley, the soil is sufficiently permeable so that soil reclamation by leaching is feasible. The trouble is that it is difficult to convince the average Iraqi (as is the case with the average American) that it is in his interests to spend the money for drainage. Money spent for drainage seems to be of somewhat theoretical benefit, and certainly of no immediate direct benefit. This is the way it has

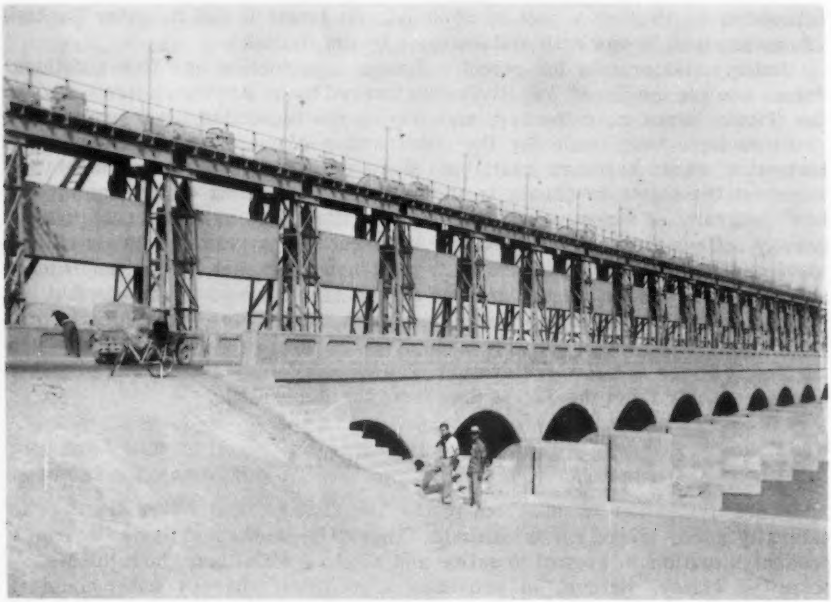

FIG. 5.—WARRAR REGULATOR, CANAL INLET CONTROL STRUCTURE DELIVERING WATER TO LAKE HABBANIYAH FROM THE EUPHRATES RIVER

been for thousands of years. A long time ago, the Mesopotamians realized that salts collecting in the soil were partly responsible for its decreasing fertility, but each generation thought of immediate direct benefit and so neglected to do anything about drainage. This is happening today in the United States and in some parts of western Europe.

In modern Iraq there are men who are well aware of the necessity for agricultural drainage, but, as in other parts of the world, they are having less than spectacular success in getting what they consider proper recognition of this in the form of money appropriated for that purpose. During 6000 yr of

irrigation, 4000 B.C. to 1950 A.D., Iraq had no artificial drainage for agriculture, and no provision for any. The year 1951 saw the beginning of a program. For the period 1950-56, the total irrigation-drainage-reclamation construction budget was set at 61 million dinars (171 million dollars). Of this, 22.3 million dinars was for new dams and barrages, 20.3 for new canals and hydraulic appurtinances, 10.3 for new flood control works, 4.1 for deep wells, and 4.1 for main drains.

This was nearly 40% of the 155,000,000 dinar total development budget for the period 1950-56. Of the 155,000,000 dinars budgeted, only about 100,000,000 was actually spent, owing partly to the disrupting effects of the March, 1954, flood. The revised development budget for 1955-60 was set at 500,000,000 dinars. The percentage for irrigation-drainage-reclamation (including dams) was set at about 32% of the total, as compared with the 40% in the 1950-56 budget. The decreased percentage reflects a switch in emphasis from major dams to short-term projects. After the 1958 revolution, the new regime decided to emphasize this shift still further, reducing major dam building to a minimum, but continuing to emphasize local irrigation-draingae-reclamation projects as before, including diversion structures, canals, and ground-water development.

With 4.1 million dinars budgeted for main drains, the drainage problem in Iraq was getting some serious attention at last, although it continued to lag behind other features of agricultural development.

IRRIGATION PLANNING AND ADMINISTRATION

It is hard to say whether governmental development or irrigation development came first in ancient Mesopotamia, although they probably developed together. Since the development of large scale irrigation in Iraq was not a simple matter, but required river diversion structures, and long canals of large capacity that fed laterals of various sizes, a considerable organizational effort was involved. Also, there was the matter of seeing to it that the rights of the individual farmers were protected, so that each man got his fair share. The Babylonian King Hammurabi's laws (about 1800 B.C.), considered to be some of man's earliest written laws, had a provision by which a farmer had to pay damages if, by his irrigation operations, he damaged his neighbor. The individual farmer had legal irrigation rights, and in addition there was a national overriding administration that provided for a work force to build the diversion works and the canals. The fact that an ever higher degree of organization was required for greater general prosperity must have been a major factor in the development of this ancient civilization.

Through the various changes in the administrations, first the Sumerians, then the Babylonians, the Assyrians, the Persians, the Arabs, the Turks, the British, and now the Iraqis, the quality of the administration has been reflected in the irrigation development. The year 1918 found the irrigation developments in Iraq in poor condition. Little new construction work had been done for centuries, although the Turks had recently completed one diversion dam (Hindiya Barrage, 1913), and had plans for another, based on the studies of the British engineer, Sir William Willcocks.

Under the British Mandate, after World War I, relatively rapid progress was made in promoting modern ideas, and then, in 1932, when Iraq became fully independent, she continued to receive British technical aid and advice in

the field of irrigation and water development. The thing lacking for really rapid progress was money for education and for construction. The oil production brought the money. With the oil money, the Iraqis in recent years have been able to expand local education and to send more students abroad. Over 3000 Iraqi students were enrolled in foreign colleges in 1956, mainly in Britian and the United States. Alro, they have been able to engage more engineers and constructors from various foreign countries. Represented in recent years have been many from the United States (dams, general irrigation plans, a soil survey, a ground-water survey, well drilling, a hydrological survey) and the British (dams, a soil survey, canals, irrigation control works), and lesser numbers from other countries including France, Germany, Italy, Holland, Denmark, and Switzerland.

Until 1958, two of the Development Board members were not natives of Iraq—one from the United States and one from Britain. Until the 1958 Iraqi revolution, the influence of Russia was negligible, but since then, Iraq has signed an agreement with Russia for major financial and technical aid for industrial development.

In addition to the degree of efficiency of the various administrations, there have been several pervading trends and influences that have helped shape the irrigation development of Iraq. Among these are pan-Arabism and pan-Islamism, which, since the 7th century A.D., have been powerful influcences in spreading knowledge of all kinds among the countries of the Middle East. For this reason the influence of Egyptian irrigation practice ranks with the influence of the Turkish and British administrations in its influence on Iraqi practice. Another factor is the natural tendency, in any land of uncertain water supply, for the development of large estates as the smaller land holders are squeezed out during the bad years. Iraq, being subject to floods and to draughts, has been a difficult place for the small independent farmer to maintain himself, and so there were not many of them. The land tended to be owned or controlled by a relatively few hereditary tribal Arab sheiks and Kurdish agas, and by absentee landlords, who became wealthy while the peasant farmers remained in a state approximating serfdom. Since 1950, several irrigation projects have aimed at opening up new lands for small farms. Nevertheless, at the time of the July 1958 revolution, more than 90% of the land was controlled by a few hundred men. This was one of the sources of discontent leading to the revolution.)

A third important influence has been the historic Arab aversion to mountains. Under some of the previous rulers, such as the Assyrians, Persians, and Turks, something approximating the entire drainage area of the two rivers was under one central government, but the Arabs love the valleys, and they were never able to spread their population and culture very far into the mountains. This resulted in the limiting of Iraq to the big Mesopotamian valley plus a relatively small portion of the mountainous part of the drainage area of the two rivers, More than one half of the total combined drainage area of the two rivers lies outside of Iraq. This, of course, is a block to full independent development of the safe yield of the rivers for Iraqi use, and makes necessary close cooperation with foreign countries if the maximum benefit is to be achieved.

A start toward this close cooperation has been made. In recent years, Iraq has received rainfall and stream-flow data for numerous stations in Turkey, plus several in Iran. When floods threaten, Iraq has received warning by telegraph from four upstream stations in Turkey and two in Syria.

In 1913, a treaty was signed with Iran relative to the rights of Iran and Iraq to the supply for a river that enters Iraq from Iran at Mandali, east of Baghdad. In 1948, a treaty of friendship with Turkey contained a provision for cooperation in the control of the Tigris and Euphrates Rivers. Also in 1948, a United Nations Food and Agriculture regional conference in Cairo passed resolutions calling on Syria and Iraq to plan together for the utilization of the Euphrates River. From 1955 to 1958, the Baghdad Pact brought Iraq, Turkey, and Iran into consultation on river planning.

Modern Iraq has the blue print for a good organizational structure for the administration of its irrigation. All that is required, for outstanding achievements in irrigation, is political tranquility and time, plus a continuation of the money supply from oil. As of 1955, the principal operating agency was the Department of Irrigation, which had responsibility for the administration of operations for both flood control and surface irrigation (but not ground water, which came under the Geological Department). The long-range planning and development was under the politics-minded government ministries until 1950, when the Development Broad, an independent agency responsible dirrectly to the prime minister, took charge of that work. After the revolution in 1958, the Development Board was dissolved. The Development Board's operations were considered to be honest and efficient, but the Board became unpopular with the Iraqi people because of its emphasis on long range planning that would benefit the present-day Iraqi's children and grandchildren a great deal, but the present-day Iraqi himself only moderately. The dissolution of the Development Board was followed by the policy of de-emphasizing long-range projects such as the big multi-purpose dams, and giving greater attention to projects of relatively quick benefit, such as housing, roads, municipal water supply, small industries, and the improvement of the canal systems.

The Iraqis, is developing their plans for full development of their country's great potential for irrigation, have at their disposal the results of a soil survey, 71 yr of rainfall records, and 41 yr of stream discharge records. The older records are fragmentary, but for the last two or three decades the records are nearly complete for some of the stations. Price-type cup-vane current meters have been used since 1921; previous measurements were by float. Low water only was gaged until 1921, when cable facilities were established for making flood measurements.

As of 1955, Iraq had 65 rain gages (2 of them recording) and 76 stream gaging stations (one of them equipped with an automatic water stage recorder). (Early in the 10th century A.D., the Arabs had a graduated river gage 54 ft high on each side of the Tigris River at Baghdad, but no records remain. In the eleventh century A.D., they produced a book titled "The Flow of Underground Water," possibly the first book on hydrology.) In 1955 Iraq had a general survey of the ground water aquifers based on surface geology and well logs, the results of a hundred pumping well tests, hundreds of tests of river water and ground water for quality, thousands of miscellaneous observations of ground-water elevation, and plans for establishing a regular program of periodic ground-water observations. Also, Iraq had tentative plans for a program of snow surveying, and for establishing evaporation stations.

CONCLUSION

The Iraqis of today have the benefit of a 6,000-yr trial-and-error experience in irrigation methods and in the development of water resources. In

addition, they have the benefit of the great advances in irrigation engineering that have been developed in other parts of the world in recent decades. They have at present three important ingredients for success: (1) a population that is basically strong, intelligent, and ambitious; (2) a great amount of land of undeveloped potential for irrigation; and (3) a supply of money from oil to finance the work.

As is true in many other parts of the world, including the United States, the biggest problem in Iraq today is to gain public support for doing what to the irrigation engineer obviously should be done, especially the consideration of long-range benefit in addition to immediate benefit, through such things as developing a strong, well-paid staff of engineers, providing for adequate agricultural drainage, guarding against over-development of ground-water basins, and the establishing and maintaining of a strong program of collecting basic agricultural and hydrologic data for the most efficient planning and operation of the work.

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DRAINAGE, A VITAL NEED IN IRRIGATED HUMID AREAS

By Albert L. King[1]

SYNOPSIS

Total rainfall in humid areas appears to be adequate for almost all purposes. The rainfall pattern, however, is constantly varying and unpredictable. The variability in amount, rate of fall, and time of rains causes droughts on the one hand and flooding of level lands on the other. Supplemental irrigation solves the problem created by droughts, while adequate drainage systems offer a solution to the drainage problem. Where supplemental irrigation is practiced, drainage is as important a factor as the provision of water for crops.

SETTLEMENT OF HUMID AREAS AND RESULTANT PROBLEMS

Settlement of new countries normally takes place in coastal areas and spreads inland along waterways for several reasons. Rivers which overflow their banks build up the well-known alluvial flood plain. In settling a country, some people move into the flood plain because they associate this feature with geologic ages. The valley is very fertile and is accessible through the river channel when other means of communication or transportation may be lacking, while at the same time it provides one easily defended side of the homestead or settlement. The relative infrequency of devastating floods and the natural optimism of settlers make the occupation of the flood plain a compelling inducement.

Flood plains are more or less level, and they offer the most fertile areas for agricultural pursuits. Many areas are swampy or at least poorly drained;

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all are subject to occasional overflow and need protection from floods. The need leads to the construction of levees along major portions of many rivers and also along many of the tributary streams. This work is so extensive that it is a regional problem, rather than local. The lower Mississippi River levees are an excellent example of such a completed project.

These levees, along with associated channel changes, permit flood waters to be carried off without damage to protected areas. They lead, however, to the necessity for somewhat similar protection along tributary streams, and to the provision of improved or additional new drainage facilities in many of these areas. In addition, it is found to be economically feasible in many cases to drain many swampy or lowland portions of the protected areas. The facilities are needed to lower the water level below the normal root zone of crops in the area as well as to carry off excess surface water resulting from heavy local rains. In many fairly level areas, drainage is necessary because: (1) surface water from nearby higher land may collect there; (2) soil structure may be such as to permit underground water to drain from higher to lower land and tend to keep it wet; (3) coastal areas may be subject to the effect of tides; and (4) level land may have thick beds of heavy clay near the surface, especially those lands where much irrigation is applied (as in rice culture).

A good example of an area formerly frequently flooded, and for the most part poorly drained, is the St. Francis River basin in Arkansas and Missouri The basin is immediately west of the Mississippi River and extends from about 50 mi south of St. Louis to about 50 mi southwest of Memphis. It is about 7,000 sq mi in area, with about 1,500 sq mi of the upper basin being hilly. Runoff there is rapid and outflow is controlled to some extent by operations at Wappapello Dam.

The remainder of the basin is more or less level. It was swampy in many places and on the whole was poorly drained. Two factors brought about this condition: (1) in the last several hundred years, the Mississippi River has moved eastward to its present location, leaving a poorly-drained area roughly 30 mi wide and 150 mi long with many horseshoe lakes, sloughs, and swamps; (2) the New Madrid earthquake, which occurred about 150 yr ago, caused much of the land in the upper portion of the area to sink several feet, thus aggravating the drainage problem. The entire basin is protected from Mississippi River floods by a massive levee, but the lower end of the basin is subject to backwater when the Mississippi is at high stages.

The land was so fertile, with markets close by, that action was taken several decades ago to drain the Missouri portion of this very level area. It is covered by a network of drainage ditches, diversion channels, local levees, and other controls, and is now an intensively cultivated agricultural area.

The Arkansas portion of the basin also has many drainage facilities, including an inverted siphon, but it is subject at times to Mississippi River backwater. Plans call for the present St. Francis channel to be used as a "sleeve" through which water from the upper St. Francis will be fed directly into the Mississippi. The remainder of the area, the "interior" portion, will be drained by present tributaries, supplemented by some new channels now under construction. After completion of the project, runoff will flow naturally into the Mississippi, except in high water periods, when it will be pumped over a structure which will block the Mississippi River backwater from the area. The total area in the St. Francis basin thus protected by levees and drained in the manner just described is on the order of two and one-half to three million acres.

Thus, upon the completion of protective and drainage facilities along a stream and its major tributaries, the regional problem, it is necessary for interests in the subtributaries to take similar remedial action, the local problem. This local problem soon reaches out to the individual farm or densely populated area, where coordinated action by all interests is required. This action points directly to the setting up of drainage districts with necessary legal status. Cities in the area are now able to provide adequate means for the disposal of sewage and industrial waste. Farmers can now install drains which meet their individual requirements and be fairly certain that crops will not be flooded or drowned out by a too-high water table. Intensive farming becomes commonplace rather than the exception.

Looking at the overall problem, one is reminded of the human body, an example of possibly the best integrated entity. The main river is the torso, the tributaries are the arms and legs, and the subtributaries and sub-subtributaries are the hands and fingers and the feet and toes.

INTENSIVE FARMING FOCUSES ATTENTION ON WEATHER VAGARIES

Now that his most fertile land is protected from flooding and is well-drained, the landowner begins intensive farming. He plans his program on the assumption that there is enough rainfall in humid areas to produce any desired crop. In a short time, however, the landowner finds that crop yields are quite variable and depend to a large extent upon the pattern of rainfall during the growing season. Although annual rainfall, and in most cases monthly, appears to be more than enough for the growth of crops, he finds that it quite frequently does not fall at the time most needed, and that it often falls at a rate which is not the most advantageous. Droughts occur in most seasons while in those same seasons there are often such heavy or prolonged rains that crops are damaged or destroyed. The drought periods can be overcome by supplemental irrigation, while the runoff from excessive rains can be carried off by a drainage system such as described above.

It is important that every farmer provide adequate drains for each of his fields; it is imperative if he irrigates. With irrigation, soil moisture is maintained at or near the optimum level for best crop growth, and it is necessary that provision be made to take care of any heavy rain which might fall soon after a crop has been irrigated. Otherwise the crop may be destroyed or at least damaged. In addition, adequate drainage will remove soluble salts, prevent stagnation of soil water, make the soil more firm or solid, permit a better supply of air to reach plant roots, and allow the soil to warm up more quickly in spring. A wet soil tends to make roots develop too near the surface; a soil with proper drainage will tend to cause roots to go deeper to a depth where a more constant supply of moisture is available, thus minimizing the effect of rapid moisture changes near the surface.

A complete knowledge of the history of water and its actions will enable the engineer to make the best decisions in irrigation and drainage problems. The nature, behavior, and conservation of water in agriculture are subjects covered in considerable detail in "Water," the 1955 Yearbook of Agriculture, and it would be well for the drainage engineer to become familiar with the many facts presented in the book.

Some factors which determine the crops to be grown in a specific area are the type of soil and its depth, the normal rainfall, the relative humidity, the

average and range in temperatures, the length of growing season, the normal percentage of possible sunshine, and the normal wind. Man can do little, or nothing, about these factors except for the fact that he can overcome most of the effects of the variability of rainfall.

A study of the various aspects of precipitation will show facts which the farmer must face to provide optimum moisture conditions in his fields. The study will show (1) that he will experience droughts and will need supplemental irrigation, and (2) that his land will require adequate drainage to take care of heavy rains which fall at more or less frequent intervals.

Although some long-term values must be considered, the analysis is based primarily upon rainfall in the 10-yr period 1949-1958[2] at eight locations, each of which may be considered to be representative of a considerable portion of the humid area which leans toward agricultural pursuits. The locations are Memphis, representative of western Tennessee; Ft. Smith, of western Arkansas; Alexandria, of central Louisiana; Selma, of south-central Alabama; Columbia, of central South Carolina; Albany, of southwest Georgia; and Moline and Mt. Carmel, of northwestern and southeastern Illinois, respectively. The record at each of these stations is an example of the specific conditions an individual farmer might experience. The averages and extremes are applicable to an average farmer in the humid area and will enable him to calculate the advantage or disadvantage of modifying his farming practice. For the greatest benefit, the individual farmer should keep his own daily record of temperature and rainfall. He is familiar with his soil, knows the crops he will grow, and will be able to adjust his schedule to meet weather conditions as they occur.

For this paper, conditions which were experienced at particular locations in the humid area were studied. Conclusions were then drawn after considering averages at eight such points. Much research has been done by others considering averages from a large number of stations in a large area, with valid general conclusions being reached by considering these averages.

DROUGHTS

There is little or no correlation between monthly or annual rainfall and droughts, except when rainfall for considerable periods is much below normal. Serious droughts have been noted in periods when total rainfall was above normal. In many cases, the rain fell at excessive rates, much of it ran off, and crops received little permanent benefit. Daily precipitation values must be studied in detail to evaluate the effect of rainfall.

The moisture requirement of a particular crop is the determining factor in defining a drought period. The minimum number of consecutive days considered, a drought will vary widely and will depend upon the particular crop and its stage of development. Cotton is grown in much of the humid area, and for this study, a definition of a drought for cotton is given as an example. The National Cotton Council of America agrees that it is a practical and workable definition. Corn has an earlier and shorter period of maximum growth, and the harvesting period is not as critical as that of cotton. A drought period, for this study, is defined as 14 or more consecutive days with less

2 "Climatological Data," U. S. Weather Bur., for various states and years.

than 0.25 in. of rain on any one day.[3,4] The number of drought days in a month or year is the sum of the drought days in the various periods in those times. In some of the longer drought periods, some rains slightly heavior than 0.25 in. have been disregarded, as a rain of that amount is totally ineffective in breaking a serious drought. The actual growing season for cotton extends roughly from April through September, with the harvest season extending to about the middle of November.

Droughts come in all seasons of the year, although in no regular or predictable pattern. Table 1 shows that a total of 499 drought periods occurred in the 10-yr period 1949-1958 at the eight stations selected for study, with an average of 6.24 periods per station per year. The length of the periods varies from 14 days (the minimum by definition) to 81 days, with an average length of about 23 days per period. The median period is about 20 days. The study shows that location in the humid area appears to have little effect upon the number or length of drought periods. The frequency of drought periods of various lengths is indicated by the mean curve in Fig. 1.

At first glance, it would seem to be sufficient to consider only those droughts which occur during the growing season of the particular crop under

TABLE 1.—DROUGHT PERIODS, 1949-1958

Station[a]	No.	Length, in Days	
		Average	Limits
(1)	62	24	14 - 75
(2)	56	22	14 - 59
(3)	75	23	14 - 59
(4)	58	23	14 - 72
(5)	61	23	14 - 59
(6)	59	23	14 - 68
(7)	63	23	14 - 81
(8)	65	24	14 - 54

[a] Stations: (1) Moline; (2) Mt. Carmel; (3) Ft. Smith; (4) Memphis; (5) Alexandria; (6) Selma; (7) Albany; and (8) Columbia.

study. Further study, however, shows that all droughts during the entire year must be considered for two reasons: (1) a prolonged drought in the spring will reduce the moisutre content to such an extent that the soil may be difficult to work. If a seed-bed has been prepared, there will not be enough moisture to sprout seed. A drought in the fall hinders preparation of land for planting fall and winter crops and prevents germination of seed at the optimum time. At the same time, however, a dry fall is favorable for harvesting crops which mature at that time. (2) In many parts of the humid area, especially in the southeast half, crops are grown throughout the year. The moisture requirement varies with each crop and with the stage of development of the crop. A

[3] "Weather Facts as Related to the Place of Irrigation in Cotton Production in the Mid-South," by A. L. King, U. S. Weather Bur., a mimeographed paper presented July, 1954 at the Eighth Annual Beltwide Cotton Mechanization Conf., Little Rock, Ark.

[4] "Weather Facts, Drought Days, and Supplemental Irrigations," by A. L. King, U. S. Weather Bur., October, 1954, a mimeographed paper presented at serveral irrigation workshops.

drought in the planting period can be disastrous; one in the period of maximum growth and fruiting will reduce yield materially; one in the harvest season, however, may be necessary or at least highly desirable.

Table 2 summarizes the number of drought days experienced in the 10-yr period under study. The average monthly number is about 7 from February through April and about 10 from May through July. The number increases rapidly from 14 in August to a peak of about 21 in October, then decreases to about 15 in November and 12 in December and January. In the northern portion of the humid area, or in any area where no crops are grown during the winter months, the number of drought days during the "no-crop" period may be disregarded except for academic reasons.

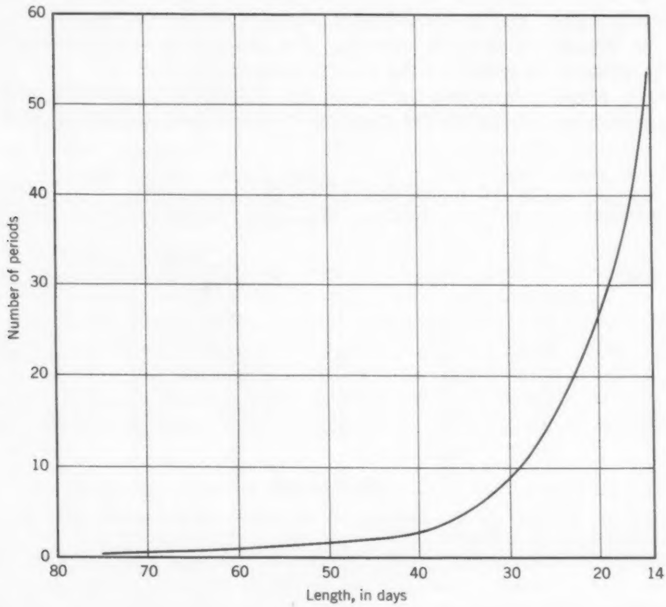

FIG. 1.—DROUGHT PERIOD FREQUENCY, 1949-1958

The frequency of exhaustion of moisture supplies during the growing season and the attendant water deficits have been determined for nine southern states by C. H. M. van Bavel. A summary of the method used and the results obtained is given elsewhere.[5]

SUPPLEMENTAL IRRIGATION

Knowing that droughts occur, the farmer now investigates the possibility of overcoming them. He finds that supplemental irrigation, if economically

[5] "Water Deficits and Irrigation Requirements in the Southern United States," by C. H. M. van Bavel, Journal of Geophysical Research, October, 1959.

feasible in his operations, will provide the moisture needed by his crops.

Supplemental irrigation is used to keep soil moisture above a predetermined minimum and at such a level that the crop will grow at the optimum rate. Without irrigation, antecedent conditions over a considerable period of time play a most important role. With irrigation, the role is minor or nonexistent, since the ground is kept in prime condition at all times, in winter as well as in summer. In the warmer sections of the humid area, both fall and winter crops are grown. They can be irrigated if necessary, while water can be withheld from those crops in which harvesting operations can best be carried out with a drier soil.

Various approaches have been made to the problem of trying to determine when to irrigate. Basically, all methods must balance the soil moisture loss with water added to the soil either from rainfall or irrigation. The problem is almost infinitely variable, but the main factors to be considered are surface runoff, underground drainage, evaporation, and transpiration. The mean monthly and annual evaporation amounts from some Class A stations in the humid area[6] are given in Table 3. The evaporation is from a water surface

TABLE 2.—AVERAGE MONTHLY AND ANNUAL DROUGHT DAYS, 1949-1958

STATION	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Moline	15.1	10.6	11.3	7.8	9.3	2.6	5.3	11.5	17.2	19.6	21.8	19.3	151.4
Mt. Carmel	8.2	8.8	6.1	7.3	6.4	5.4	8.3	15.3	16.9	19.0	9.8	11.0	122.5
Ft. Smith	15.3	9.8	10.4	8.3	7.6	16.1	16.6	15.7	17.5	19.9	17.0	19.5	173.7
Memphis	7.5	2.0	4.4	5.5	13.1	10.6	10.4	18.1	17.1	19.9	11.0	15.7	135.3
Alexandria	8.1	5.3	5.6	6.0	13.1	12.6	12.6	19.9	20.4	19.9	10.8	8.4	142.7
Selma	12.7	8.2	4.5	4.5	12.7	8.5	6.8	16.3	20.5	24.8	14.3	4.8	138.6
Albany	17.3	7.6	7.3	8.0	15.8	9.7	6.8	9.7	13.6	20.7	19.1	11.3	146.9
Columbia	7.8	7.6	3.9	12.4	17.5	9.5	14.3	9.0	16.2	25.1	16.8	12.9	153.0
Mean	11.5	7.5	6.7	7.5	11.9	9.4	10.1	14.4	17.4	21.1	15.1	12.9	145.5

under standard conditions for such stations and are given to show the magnitude of evaporation. Some researchers use 0.7 as a factor to convert open-water evaporation to values applicable to vegetative surfaces. The following comparison gives some indication of the evaporation from a water surface as compared with that from soil. C. S. Slichter found that evaporation from a water surface in slightly less than one certain month was 10.90 in. From cultivated soil, with the water table one foot below the surface, it was 4.88 in., and from uncultivated soil, it was 5.83 in. Evaporation from soil with a capillary lift of 2 ft was 2.23 in., and for a lift of 3 ft, 0.80 in.[7] One principal effect of drainage is to reduce evaporation. Drainage presupposes an excess of moisture on the surface and in the upper few feet of soil, the layer from which evaporation takes place. By removal of surface water and by taking away gravity water from the upper layer of soil, drainage materially reduces the opportunity for evaporation.

If water for irrigation is to be obtained from a reservoir, the engineer must take into account evaporation from the reservoir. Data obtained from

[6] "Mean Monthly and Annual Evaporation from Free Water Surface," Tech. Paper No. 13, U. S. Weather Bur., July, 1950.

[7] "Elements of Hydrology," by A. F. Meyer, John Wiley & Sons, Inc., New York, N. Y., 1928.

TABLE 3.—MEAN MONTHLY AND ANNUAL EVAPORATION (INCHES), CLASS A STATIONS

Station	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Springfield, Ill.	8	. . .	. . .	. . .	5.19	5.90	6.98	8.39	7.22	5.67	3.72	1.97	. . .	. . .
Hope, Ark.	12	2.34	2.66	4.38	5.54	6.41	7.10	8.05	7.63	5.97	4.68	2.67	1.97	59.48
Hackberry, La.	10	3.53	3.64	4.78	6.32	8.09	7.82	8.62	8.04	7.02	5.98	3.78	2.89	70.51
Crowley, La. (BPI)	39	2.49	2.68	3.89	4.80	5.92	6.19	5.86	5.74	5.12	4.43	3.23	2.40	52.75
Vicksburg, Miss.	7	1.67	2.10	3.79	4.96	5.95	6.60	7.13	6.68	5.06	3.91	2.34	1.42	51.61
Fairhope, Ala.	14	1.98	2.36	3.64	4.91	6.12	6.20	5.88	5.61	4.53	3.68	2.37	1.62	48.90
Orlando, Fla.	7	2.88	3.78	5.35	6.56	8.00	6.87	6.83	6.06	5.14	4.82	3.43	2.67	62.39
Experiment, Ga.	12	2.08	2.54	4.39	5.81	7.34	7.76	7.03	6.28	5.42	4.21	2.58	1.95	57.39
Murphy, N. C.	14	1.03	1.49	3.00	4.32	5.54	5.88	5.74	5.07	4.10	2.89	1.64	0.90	41.60

evaporation stations throughout the United States has been summarized[8]. Of special interest are (1) a table giving average annual, or seasonal, evaporation at 78 Class A stations, and (2) maps of the United States showing (a) average annual Class A pan evaporation in inches; (b) average annual lake evaporation in inches; (c) average annual Class A pan coefficient in percent; (d) average May-October evaporation in percentage of annual; and (e) standard deviation of annual Class A pan evaporation in inches.

Evapotranspiration, the end product of a large number of weather and plant factors, has been the object of study by many researchers, among them being Thornthwaite, Penman, van Bavel, and many others.

A simplified and streamlined method, the depletion method, may be used easily by any individual to determine the approximate time to irrigate. A record of the daily rainfall and a running moisture-depletion total, which is assumed to include both evapotranspiration and underground drainage, should be kept. In the Mid-South, the method has been used at 14 stations for more than 15 yr and the times of irrigations indicated by the method have agreed very closely with the times of actual irrigations. This fact tends to prove that the assumptions made are basically correct.

Table 4 is given as an example of the application of the depletion method in determining when to irrigate. Average soil and weather conditions other than rainfall must be assumed to set up specific factors to be used. Daily precipitation amounts at Alexandria, La., for 1957[2] are entered under the columns (1) in Table 4. An assumed average daily moisture-depletion amount during each month is entered in line (B); these amounts vary from 0.10 in. per day in the cooler months to 0.20 in. per day in summer. After taking rainfall into consideration, the daily cumulative depletion is given under the columns (2). When the cumulative depletion reaches the total given in line (A), an irrigation is indicated. The greatest allowable cumulative amounts vary from 1.50 in. in the cooler months to 2.00 in. in summer, and to 2.25 in. in the spring and fall. The date of an indicated irrigation is shown in Table 4 by the entry "XXXX," as shown on June 16. The entry "????" is used to show that an irrigation is of doubtful value, because rain came shortly after that time, as shown on August 31. The cumulative entry on January 1 is 100, which indicates the deficiency carry-over from the last day of the previous month was 90 (0.90 in.). With no rain on January 1, 10 is added, giving the 100 entry; it is 110 on January 2. On January 3, the entry would have been 120 if no rain had fallen; 0.15 in. did fall, however, so the entry is 120 minus 15, or the 105 actual entry.

The depletion method was used for the entire 10-yr period of study at the eight selected stations. Results are given in Table 5. The total number of irrigations per month and year was calculated for each station. The irrigations of doubtful value are indicated in parentheses. There was not a single month in the year in which at least one irrigation was not required at some time during the 10-yr period. The average number of irrigations varied from about 0.4 per station per month in February, March, and April, to about 2.0 in August. On an annual basis, the average was about 12 per yr or about one irrigation per station per month. These irrigations were necessary to maintain the moisture content of the soil at an optimum level throughout the entire root zone.

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[8] "Evaporation Maps for the United States," Tech. Paper No. 37, U. S. Weather Bur., 1959.

[9] First presented by A. L. King at the Fifth Annual Sprinkler Irrigation Meeting held at Virginia Poly. Inst., Blacksburg, Va., March, 1956.

TABLE 4.—EXAMPLE OF DEPLETION METHOD USED IN

(A)	1.50						2.25					
(B)	.10		.10		.10		.15		.15		.20	
Month	Jan.		Feb.		Mar.		Apr.		May		June	
Day	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
1		100	.07	88		97	1.41	0	.19	90	.88	0
2		110	.19	79		107		15	.73	32	.65	0
3	.15	105	.02	87	1.76	0		30	.03	44	.98	0
4	.04	111		97		10	1.17	0	T	59	.10	10
5		121		107	.02	18	.28	0		74		30
6		131		117		28		15		89	.38	12
7		141		127	T	38	.04	26		104		32
8	XXX			137		48		41		119		52
9		10		147		58		56	1.25	9		72
10		20	XXX		T	68		71	.01	23		92
11		30		10	.10	68	1.10	0	T	38		112
12		40	.06	14	1.39	0		15		53		132
13		50		24		10		30		68	T	152
14		60		34		20	.03	42		83		172
15		70		44		30		57		98		192
16	T	80	1.68	0		40	.70	2		113	XXX	
17		90		10	.19	31		17		128		20
18		100	1.77	0	1.00	0		32		143		40
19		110	T	10		10		47		158		60
20	.07	113		20		20		62		173	.26	54
21		123		30	1.55	0	.05	72		188	.26	48
22	.48	85		40		10	T	87		203	.03	65
23		95	.06	44	1.78	0	T	102	.20	198		85
24	.30	75	T	54	.67	0		117	.53	160	1.40	0
25	.21	64	.07	57		10		132	T	175		20
26	.10	64		67		20		147	.17	173		40
27	.05	69		77		30	.10	152		188	.89	0
28	.07	72		87	T	40	.22	145		203	3.25	0
29		82				50	.24	136		218		20
30		92				60	.57	94	???			40
31	.17	85			2.13	0			.08	7		

There were 960 station months in the period under study. No irrigations were required in 263 (about 27.4%) of these months, an average of about 3.3 per station year; of this total, 176 (67%) were in the period January-April, inclusive, with only 17 (6.5%) being in the period June-September, the months when most summer crops have the maximum water requirements for optimum growth and fruiting. As a contrast, the number of irrigations required in the June-September period totalled 542, an average of about 1.7 per station per month. There were 286 months (about 30%) in the 10-yr period in which two or three irrigations were required. The greatest annual number of irrigations indicated at any station was 19 at Moline in 1956; the average at all stations, 16.5; the least number, 6 at Memphis in 1957; the average at all stations, nine. Of the 1,028 irrigations indicated at all stations, 113 (about 11%) were of doubtful value because significant rains fall shortly after the times of irrigation. Adequate drainage is of prime importance in these 113 cases to prevent crop damage; they are included in the total number of times (1,039) significant surface drainage was needed, as shown in Table 11.

DETERMINATION OF TIME OF IRRIGATIONS, ALEXANDRIA, LA., 1957

2.00						2.25				1.50	
.20		.20		.20		.15		.15		.10	
July		Aug.		Sep.		Oct.		Nov.		Dec.	
(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	60	.02	57	.05	15		147		129		96
	80		77	.31	4	.05	157		144		106
.03	97		97	.94	0		172	.21	138	.05	111
	117		117		20		187	.11	142		121
	137		137		40		202		157		131
	157		157		60		217	1.99	0		141
	177		177		80	XXX		.77	0	1.36	15
	197		197	.05	95		15	2.25	0		25
XXX		.23	194		115		30		15		35
	20	XXX			135		45		30		45
	40	T	20		155		60		45		55
	60		40	1.48	27		75	.10	50		65
	80		60		47		90	3.38	0		75
	100		80		67		105	.40	0	.25	60
	120		100		87	.52	68	.03	12	.06	64
	140		120	.30	77	3.19	0		27		74
	160		140	.21	76		15	.36	6		84
.20	160		160		96		30	1.26	0		94
1.62	18	.04	176		116		45		15	1.70	0
.29	9		196	.47	89		60		30		10
.08	21	XXX			109	.45	30	.40	5		20
.47	0		20	.15	114	1.07	0	1.30	0		30
	20		40	.16	118	3.66	0	.22	0		40
	40		60		138		15	.80	0	.83	50
1.46	0		80		158		30		15		0
	20		100	1.20	58		45		30	.02	8
	40		120	.06	72		60		45	.24	0
	60		140		92		75	.04	56	.89	0
	80		160		112		90		71		10
.11	89		180		132	.06	99		86		20
.70	39	???					114			.09	21

Much additional research is needed in the irrigation field. An article by H. H. Engelbrecht,[10] may help those who are interested in this phase of the overall problem.

RAINFALL AND DRAINAGE

The land is now protected by levees and flooding from streams is eliminated; lowlands and swampy places have been drained; crops are being grown. The farmer finds that crop yield is cut drastically in some years, and to some extent in almost every year, by droughts. He eliminates this uncertainity by supplying water during dry periods by supplemental irrigation. The land is kept in prime condition and crops grow rapidly. Just at the time it appears

[10] "The Application of High-Speed Computers in Irrigation Research," by Howard H. Engelbrecht, Bulletin of the American Meteorological Soc., November, 1959.

TABLE 5.—TOTAL NUMBER OF MONTHLY AND

Station[b]	Jan.		Feb.		Mar.		Apr.		May		June	
(1)	8	(2)	8	(1)	9	-	6	-	9	(1)	8	(5)
(2)	4	(2)	3	-	2	(1)	3	(1)	5	(1)	10	(2)
(3)	9	-	4	-	6	-	4	-	6	(1)	17	(1)
(4)	1	(2)	2	-	2	-	2	(1)	8	-	12	(2)
(5)	3	(1)	3	-	3	(1)	4	-	4	(2)	17	-
(6)	5	(2)	4	-	2	-	2	(1)	10	(1)	9	(7)
(7)	9	-	5	-	5	-	4	(1)	6	(1)	12	(4)
(8)	7	-	6	(1)	1	-	7	(2)	9	-	20	(1)
Mean[c]	0.6	(.1)	0.4	([d])	0.4	([d])	0.4	(.1)	0.7	(.1)	1.3	(.3)

[a] Parentheses denote irrigations followed shortly by more or less significant rains.
[b] Stations: (1) Moline; (2) Mt. Carmel; (3) Ft. Smith; (4) Memphis; (5) Alex-
[c] Mean number of irrigations per station per month and year.
[d] Less than .05.

that a bumper crop is forthcoming, a heavy and prolonged rain falls; the crop is flooded, resulting in a total loss in some areas and severe damage in the remaining area. The farmer realizes, too late, that he has not taken into consideration all factors in the case. He has forgotten that heavy rains can be expected from time to time and that provision must be made to take care of surface runoff from the rains. The drainage need is greater if irrigation is practiced because the moisture content of the soil is maintained at a fairly high level, thus resulting in greater and faster runoff from heavy rains. If the field had not been irrigated prior to the rain, more water would have been absorbed by the soil, with less runoff resulting. The reduction would be less than might be expected, however, because it takes considerable time for moisture to soak deeply into the soil, except possibly in the case of a sandy soil. The farmer now realizes that he must provide adequate drainage as one of the final steps in his effort to provide insurance for optimum crop yields. In planning a drainage system, it is a duty of the engineer to point out to the farmer that it is highly desirable to level the land (1) to eliminate the "low spots" which exist in so-called level fields, and (2) to establish a predetermined slope or grade to eliminate most of the effects of sheet erosion. Water from rainfall will then soak must more evenly into all portions of the field, and when irrigation is practiced, one portion of the field will not be too dry while the other portion is too wet. In addition, more rainfall will soak into the soil of a properly levelled field, with a reduction in the number of irrigation required and also in erosion of the topsoil. The capital expenditure for drainage is necessary, especially so when irrigation is practiced. A detailed study of rainfall in the humid area shows without question the need for drainage.

For the 10-yr period 1949-1958, Table 6 shows (1) the mean monthly and annual; (2) the greatest monthly and annual; and (3) the least monthly and annual precipitation[2] at the eight stations used in this study. The mean monthly amount is 3.78 in., which is almost adequate for most crops in most cases if it fell at the right times. The mean of the greatest monthly amounts, 8.08 in., is 214% and the mean of the least monthly amounts, 1.05 in., is

ANNUAL IRRIGATIONS, 1949 - 1958[a]

July		Aug.		Sep.		Oct.		Nov.		Dec.		Annual	
14	(2)	16	(3)	18	(3)	13	-	11	(1)	15	(2)	135	(20)
14	(2)	20	(2)	17	(2)	10	-	7	-	7	(3)	102	(16)
19	(1)	19	(2)	13	(5)	11	-	11	-	13	(1)	132	(11)
14	(1)	18	(3)	17	(2)	12	-	7	-	7	(1)	102	(12)
10	(1)	19	(1)	17	(2)	11	(1)	7	(2)	4	(4)	102	(15)
11	(2)	18	-	19	(2)	12	(1)	10	(1)	3	-	105	(17)
8	(2)	17	(2)	13	(2)	16	-	12	(1)	6	(1)	113	(14)
13	-	13	-	15	(1)	12	(1)	13	-	8	(2)	124	(8)
1.3	(.1)	1.8	(.2)	1.6	(.2)	1.2	([d])	1.0	(.1)	0.7	(.2)	11.4	(1.4)

andria; (6) Selma; (7) Albany; and (8) Columbia.

28% of the actual mean monthly precipitation amounts. Many months in the 10-yr period had so much total rain that crops were damaged and drainage was needed, whereas, there were also many other months with not enough total rain to sustain any crop. The average annual snowfall and temperature are also given in Table 6. At the eight stations under study, every month had a mean temperature above freezing except for two months in mid-winter at Moline and for one month at Mt. Carmel.

Records of mean annual precipitation, or even the monthly amounts in most cases, are not of much value in the design of most works for the utilization or control of water. Runoff resulting from the average precipitation can seldom be utilized. Records of exceptional conditions are of much greater importance than records of average conditions. In drainage problems, we should consider the occurrence of rains of sufficient amount and intensity to produce material runoff and to require adequate drainage. Light rains are of little significance because of the small amount of moisture involved and also because vegetation intercepts a considerable portion of such rains.

It has been estimated that rainstorms from which we receive much of our excessive precipitation cover an era about 15 mi in diameter on the average. Precipitation falls in an irregular manner, with respect to time, in a given locality. Records for a single station furnish a far less satisfactory basis for a valid conclusion regarding the frequency of given rates of excessive precipitation than the records of several stations in a general area. If an area is meteorologically homogeneous, the records of several stations in a limited area may be combined, and they are virtually equivalent to a longer record at a single station, one record supplements the other.[11]

Table 7 gives the maximum 24-hr precipitation as recorded in each month for the period of record at the eight stations under study.[12] The length of record varies from 20 to 79 yr. The greatest 24-hr amounts range from 4.77 to 21.40 in., with an average of 9.40 in. for the eight stations. Table 8 gives

11 "Applied Hydrology," by Linsley, Kohler, and Paulhus, McGraw-Hill Book Co., New York, N. Y., 1949.

12 "Maximum 24-Hour Precipitation in the United States," Tech. Paper No. 16, U. S. Weather Bur., January, 1952.

TABLE 6.—PRECIPITATION,

Station[a,b]		Jan.	Feb.	Mar.	Apr.	May	June	July
(1)	(A)	1.58	1.66	2.36	3.15	3.23	4.44	3.71
	(B)	3.56	2.72	5.06	5.87	5.90	7.13	5.60
	(C)	0.31	0.49	0.31	1.10	1.82	1.55	1.02
(2)	(A)	4.82	3.90	4.44	4.92	4.21	4.37	4.40
	(B)	13.47	8.72	7.52	8.42	7.75	8.10	12.78
	(C)	1.56	0.89	1.33	1.79	2.27	1.43	2.13
(3)	(A)	3.65	3.70	3.65	4.45	4.99	3.76	3.26
	(B)	11.33	7.94	8.52	10.32	12.09	10.40	9.50
	(C)	1.20	0.55	1.40	0.90	1.58	0.38	0.69
(4)	(A)	7.17	5.04	4.87	5.90	5.01	4.37	3.80
	(B)	15.45	9.58	9.23	12.06	10.57	10.30	6.62
	(C)	1.75	1.90	1.36	2.24	1.07	0.24	1.32
(5)	(A)	4.21	5.52	5.49	5.92	6.27	4.10	5.01
	(B)	8.00	9.45	10.59	10.43	16.90	9.08	8.08
	(C)	1.64	1.18	0.55	1.65	1.43	0.51	2.66
(6)	(A)	3.18	4.95	5.69	5.63	4.22	3.93	5.27
	(B)	5.02	8.46	9.91	9.64	8.53	5.23	11.24
	(C)	1.25	2.17	2.86	2.53	0.39	1.59	0.90
(7)	(A)	2.32	3.61	4.07	5.01	3.36	3.98	6.04
	(B)	4.77	6.49	6.10	8.07	6.32	7.69	9.98
	(C)	0.89	1.05	0.08	2.06	1.65	2.21	3.46
(8)	(A)	2.57	3.38	3.85	3.65	3.17	2.88	4.95
	(B)	4.90	6.38	7.00	5.89	6.71	6.44	11.79
	(C)	0.97	1.12	1.25	1.37	0.29	1.26	1.15

[a] Stations: (1) Moline; (2) Mt. Carmel; (3) Ft. Smith; (4) Memphis: (5) Alex-
[b] (A) Mean; (B) Greatest; and (C) Least.

TABLE 7.—GREATEST 24-HOUR PRECIPITATION,

Station	Year of record	Jan.	Feb.	Mar.	Apr.	May
Moline, Ill.	20	1.84	1.90	2.38	2.72	2.13
Mt. Carmel, Ill.	40	4.25	2.90	6.20	3.43	3.48
Ft. Smith, Ark.	68	5.42	5.56	3.83	4.98	5.80
Memphis, Tenn.	79	5.75	4.57	9.30	5.26	4.29
Alexandria, La.	53	6.16	5.20	5.40	7.00	5.46
Selma, Ala.	54	4.77	3.85	8.06	8.74	3.24
Albany, Ga.	67	4.30	4.60	6.39	7.60	4.91
Columbia, S. C.	63	2.93	4.23	2.83	3.98	4.88

1949 - 1958

Aug.	Sep.	Oct.	Nov.	Dec.	Annual	Average Snow	Average Temperature
3.82 8.00 1.05	2.05 3.85 0.49	2.20 7.43 0.04	1.45 2.99 0.60	1.72 3.82 0.50	31.37 48.60 20.20	24.3	50.2
2.36 4.71 0.10	3.32 5.60 0.85	2.91 7.32 0.97	4.02 8.22 0.81	3.78 8.80 0.54	47.45 66.59 32.63	20.4	55.7
3.11 5.83 1.42	3.25 5.88 0.06	3.02 12.05 0.57	3.15 7.03 0.59	1.92 5.42 0.53	41.91 60.78 30.57	4.5	62.0
3.32 5.75 1.46	2.94 7.22 0.28	2.89 8.16 0.66	3.38 8.89 0.69	3.92 7.44 1.72	52.61 74.78 34.79	5.2	61.8
2.78 7.41 0.10	2.73 10.28 0.34	4.16 9.00 T	4.00 13.62 0.36	5.16 9.34 1.76	55.35 73.07 36.69	2.7	67.5
2.81 7.51 0.53	3.35 7.62 0.24	1.43 3.05 0.43	2.54 5.81 0.51	5.39 11.12 2.27	48.39 54.80 30.00	0.3	66.5
3.59 6.20 0.73	4.58 11.25 0.70	1.42 3.26 0.22	2.50 8.28 0.40	3.47 9.53 0.64	43.95 59.56 32.62	0.2	66.8
6.00 16.72 1.27	4.38 8.78 0.76	1.55 2.65 0.32	2.04 7.20 0.58	3.10 7.43 0.32	41.52 53.44 27.38	2.0	64.0

andria; (6) Selma; (7) Albany; and (8) Columbia.

SELECTED STATIONS

June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Greatest
3.43 3.34	3.45 4.54	4.44 3.70	4.77 5.60	2.39 5.30	1.66 3.66	3.38 3.57	4.77 6.20
8.58 9.67	3.90 5.42	5.10 4.55	4.36 4.66	3.54 6.44	4.19 10.48	6.40 5.40	8.58 10.48
21.40 6.10	9.75 4.87	3.85 5.35	6.51 4.30	7.40 4.69	6.08 4.07	5.65 6.40	21.40 8.74
4.15 4.13	5.10 5.00	4.90 7.40	6.84 5.50	3.10 3.30	4.33 2.16	4.03 3.31	7.60 7.40

TABLE 8.—GREATEST 24-HOUR PRECIPITATION FROM STATIONS

Area	Jan.	Feb.	Mar.	Apr.	May	June
Northern Ill.	3.65	3.53	3.80	5.60	6.00	6.86
Southern Ill.	6.09	5.50	7.16	6.21	5.90[a]	5.77
Western Ark.	8.00[a]	5.56	7.50[a]	11.40	9.01	12.00
Western Tenn.	8.52	4.84	9.30	5.35	5.54	9.67
Central La.	11.13	7.30	8.15	9.95	10.00[a]	21.40
Southern Ala.	9.98	9.00[a]	10.73	10.00	8.00[a]	12.40
Southern Ga.	8.23	6.30	10.88	9.00	7.30	7.00
Central S. C.	5.85	4.70[a]	5.50[a]	7.70[a]	7.50[a]	7.04

[a] Precipitation is interpolated from amounts in surrounding areas.

TABLE 9.—COMPARISON BY HERSHFIELD AND WILSON

Storm Type	Rainfall, in inches			
	1-hr	3-hr	24-hr	48-hr
(1) Tropical	1.84	4.75	13.66	16.65
(2) Non-Tropical	2.34	6.40	14.01	14.01

similar amounts recorded at some station in the general area of the states where the eight stations are located. The record includes stations in those areas with 10 or more years of record, and the greatest amounts range from 9.15 to 21.40 in., with an average of 12.68 in., about 35% greater than the average at the eight point locations given in Table 7. The transposition of storms in a homogeneous area is standard practice in hydrometeorological work, and the engineer, as a matter of precaution, should refer to the maximum average depth of rainfall for selected time periods over areas of various sizes for all major storms in the United States.[13] If this is done by the engineer in planning drainage facilities, he will be able to consider the heaviest rainfall which can normally be expected in the general area of the project, along with such other items as factor of safety and economic feasibility.

There may be some question in the engineer's mind about the amount of rainfall in coastal areas in connection with tropical as compared with that from non-tropical storms. A comparison made in 1959 by Hershfield and Wilson[14] for such rains in New Orleans is shown in Table 9. These rains occurred (1) in October, 1937 and (2) in April, 1927. It was concluded that there is no significant difference in tropical and non-tropical storm rainfall amounts.

While the total amount of rainfall must be considered, the intensity of its fall is equally important and is of prime concern to the engineer. As an aid to him, depth-duration curves are given to serve as a guide in planning drainage

[13] "Storm Rainfall in the United States—Depth-Area-Duration Data," Corps of Engrs., U. S. Army, 1945, (see additions published in later years).

[14] Hydrologic Services Div., U.S. Weather Bur., Washington, D.C., November, 1958.

WITH AT LEAST 10 YEARS' RECORD THROUGH 1949.

July	Aug.	Sep.	Oct.	Nov.	Dec.	Greatest
6.53	9.15	9.08	5.20	5.00[a]	3.62	9.15
7.50[a]	9.50[a]	8.08	7.99	5.06	5.15	9.50[a]
8.00[a]	10.03	8.92	9.00[a]	6.47	7.00[a]	12.00
7.02	6.80	6.27	8.43	10.48	6.60	10.48
11.20	15.00[a]	11.50[a]	8.00[a]	12.50[a]	8.50[a]	21.40
12.00[a]	9.90[a]	10.25	8.03	11.20	10.15	12.40
9.90	12.00[a]	14.00[a]	9.00[a]	10.00[a]	6.08	14.00[a]
12.50[a]	11.00[a]	10.72	7.40	6.00[a]	6.00[a]	12.50[a]

facilities. Two curves for the southeastern United States[15] show (1) Fig. 2, the average percentage of 24-hr rainfall which falls in hourly increments, and (2) Fig. 3, the average of 7-day precipitation which falls in daily increments. In 1-day rains, about 65% falls in 6 hrs, 85% in 12 hr, and 94% in 18 hr. In 7-day rains, it is found that about 57% falls in 1 day, 74½ % in 2 days, 87% in 3 days, 92% in 4 days, 95% in 5 days, and 97½ % in 6 days.

Runoff increases rapidly with an increase in the rate of fall of precipitation in short periods, and Table 10 gives some indication of the rates to be expected. Maximum amounts for 1, 2, 3, 6, 12, and 24 hr are given for the 10-yr period 1940-1950, and also for the entire period of record (averaging about 50 yr) at eight locations in the humid area.[16] The choice of stations is necessarily limited to "first-order" Weather Bureau stations at which an autographic record of precipitation is available for a long period. It will be noted that in only eight of the 48 sets of comparative amounts in the table are the 10-yr record amounts the same as in the much longer records. In the remaining 40 sets, the longer-period amounts are about 8 to 113% larger than the corresponding 10-yr amounts. A comparison of the greatest 24-hr amounts in Table 10 with those in Table 8 again shows the need for considering a larger-than-recorded "station" rainfall for shorter periods, as the "area" rainfall for those periods is considerably greater in most cases. The depth-duration curves in Fig. 2 and 3 will give some indication of the proper time distribution of rains of greater amount than those shown in the tables.

Now that we know that heavy rain can be expected from time to time in the humid area, it may be well to know how many times significant surface drainage in an irrigated area is indicated. An inspection was made of the daily rainfall record at the eight stations under study. Consideration was given the time of year, antecedent conditions, and the particular pattern of rainfall. A rain of 1.50 in., for instance, in January might result in considerable runoff, while such a rain in August might give little or no runoff unless it came soon after a field had been irrigated. Table 11 indicates that considerable runoff may be expected 13 times each year (about once every four weeks) on the average

15 "Rainfall Intensity-Frequency Regime, Part 2—Southeastern United States," Tech. Paper No. 29, U. S. Weather Bur., March, 1958.

16 "Maximum Station Precipitation for 1, 2, 3, 6, 12, and 24 Hours," Tech. Paper No. 15, U. S. Weather Bur., various parts, 1954 to 1958.

TABLE 10.—GREATEST STATION PRECIPITATION

Station	Period	1		2	
Peoria, Ill.	1940 - 1950	2.23	1940	2.28	1940
	1905 - 1950	2.60	1931	3.18	1911
Evansville, Ind.	1940 - 1950	1.63	1946	2.23	1943
	1899 - 1950	2.79	1916	3.11	1916
Memphis, Tenn.	1940 - 1950	1.70	1948	2.51	1950
	1890 - 1950	3.25	1929	4.70	1929
Shreveport, La.	1940 - 1950	2.81	1940	4.02	1942
	1902 - 1950	3.15	1908	5.19	1905
Meridian, Miss.	1940 - 1950	2.54	1941	2.73	1940
	1899 - 1950	3.66	1906	3.77	1906
Apalachicola, Fla.	1940 - 1950	3.33	1946	5.01	1946
	1922 - 1950[a]	3.33	1946	5.01	1946
Macon, Ga.	1940 - 1950	2.89	1949	3.07	1941
	1899 - 1950	4.28	1923	6.55	1923
Columbia, S. C.	1940 - 1950	2.10	1949	2.57	1949
	1901 - 1950	2.28	1914	3.25	1911

[a] Record missing 1934 - 1936.

TABLE 11.—NUMBER OF TIMES SIGNIFICANT

Station	Jan.	Feb.	Mar.	Apr.	May
Moline	6	2	4	8	7
Mt. Carmel	15	11	14	13	12
Ft. Smith	10	13	9	14	13
Memphis	22	17	14	14	14
Alexandria	15	18	18	17	18
Selma	10	16	14	16	10
Albany	9	11	13	17	8
Columbia	7	10	12	9	9
Mean	12	12	12	14	11

at each station. The monthly average varies from 1.4 in April to 0.6 times in October; the annual average, from 7.5 at Moline to 17.0 times at Alexandria. In the critical growing period, April-August, inclusive, the average is 6.0 times per station; in the harvest period, September-November, inclusive, it is 2.3 times, a favorable value when a dry fall is needed. In examining published daily rainfall records, it should be remembered that the amounts are for 24-hr periods (for instance, midnight to midnight, 7 a.m. to 7.a.m., etc.), and that rains of 0.75 and 0.90 in., for instance, measured on successive days could well be one continuous rain of 1.65 in. in 24 hr or less, with considerable runoff.

A tabulation was made of the number of times when 24-hr rains of three or more, two or more, and one or more inches were measured at the eight

FOR 1, 2, 3, 6, 12, AND 24 HOURS

Hours

3		6		12		24	
3.02	1947	3.10	1947	3.54	1950	5.06	1950
3.48	1927	4.33	1927	4.69	1915	5.52	1927
2.23	1943	3.03	1945	4.47	1943	5.15	1943
3.41	1924	4.40	1924	4.82	1910	6.94	1910
2.75	1949	3.70	1947	4.75	1949	5.26	1949
5.00	1929	7.03	1934	9.67	1934	10.48	1934
4.76	1942	4.92	1942	5.54	1949	6.83	1949
6.49	1905	7.54	1905	8.52	1933	12.44	1933
2.96	1942	3.94	1942	4.80	1942	4.84	1942
4.31	1936	5.49	1936	6.73	1936	9.50	1900
7.20	1946	8.97	1946	9.37	1946	10.06	1946
7.20	1946	8.97	1946	9.37	1946	11.71	1932
3.09	1941	3.58	1943	3.90	1943	5.55	1943
6.60	1923	6.71	1923	7.92	1928	8.36	1928
2.99	1949	4.52	1949	6.77	1949	7.40	1949
4.08	1911	4.52	1949	6.77	1949	7.40	1949

SURFACE DRAINAGE NEEDED, 1949 - 1958

June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
15	9	8	4	4	4	4	75
13	13	7	9	9	11	13	140
11	7	8	12	7	8	3	115
15	12	11	6	6	9	12	152
13	18	5	6	11	12	19	170
13	15	5	11	4	8	14	136
17	19	10	11	2	6	14	137
7	12	18	14	3	4	9	114
13	13	9	9	6	8	11	130

stations under study. There were 70, 236, and 1,036 such occurrences, respectively, averaging about 0.9, 3.0, and 13.0 times per station year. Adequate drainage is needed, to prevent crop damage, in many of these cases.

CONCLUSION

Even in humid areas, all sections experience droughts, and supplemental irrigation may be used to advantage, if economically feasible and if an adequate water supply is available. Rain does not fall in many cases in proper amounts or at the times needed, although it may be adequate as far as total amount is concerned. Mamy rains fall in such amounts and at such excessive

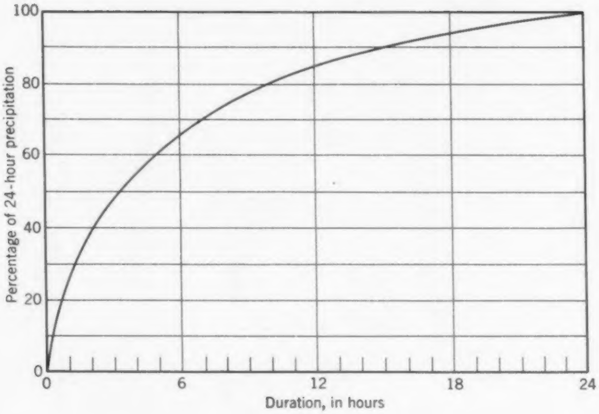

FIG. 2.—PERCENTAGE DEPTH-DURATION CURVE, SOUTHEASTERN UNITED STATES

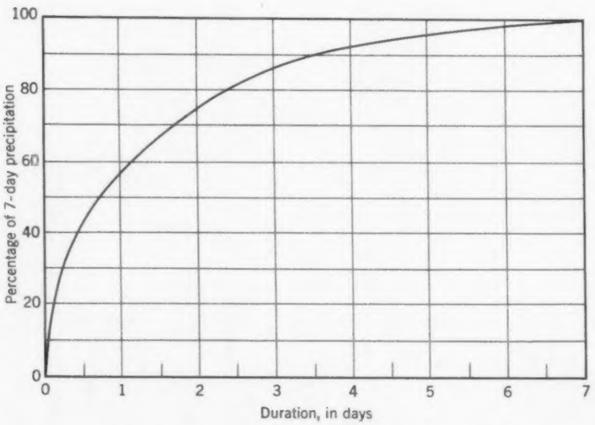

FIG. 3.—PERCENTAGE DEPTH-DURATION CURVE, SOUTHEASTERN UNITED STATES

rates that adequate drainage for the protection of crops is required for optimum yields. It must be stressed that irrigation, without adequate drainage, may be a detriment rather than an aid. Irrigation, if practiced throughout the year, keeps the soil in optimum condition and permits the growth of suitable crops in all seasons, thereby raising the standard of living in humid areas. The very rapid increase in world population makes it necessary that we have a similar increase in food production and the logical solution of the problem is to increase production in the most fertile areas near population centers. The engineer must and will meet the challenge.

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HUMID ZONE IRRIGATION IN CEYLON

By Philip P. Dickinson,[1] F. ASCE

SYNOPSIS

Humid Ceylon needs planned irrigation mainly because (1) rainfall is unevenly distributed both seasonally and geographically, and (2) the predominating rice culture requires a controlled water supply throughout the growing season in all parts of the island. Irrigation has been practiced for centuries by the storage of water in small reservoirs, and by the diversion of conserved water to bench lands and plains. It is now being extended and improved by the development of modern multi-purpose river basin projects. A major problem is the abnormal duty of irrigation water for rice culture. This has created serious drainage difficulties that require engineering attention.

INTRODUCTION

Rainfall in Ceylon varies from a maximum of 228 in. per yr in the mountains east of Colombo to a minimum of 36 in. on the south coast, and runs to well over 100 in. for much of the island. Yet irrigation has a distinguished history in Ceylon extending back 2,000 yr. In fact, planned irrigation, by the construction of storage reservoirs, is older in Ceylon than in the arid valleys of the Euphrates and the Nile where only the haphazard overflow of the rivers was relied upon until fairly recent times.

Note.—Discussion open unitl May 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 4, December, 1960.

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Why does humid Ceylon need irrigation? This paper offers an answer to the question of why, discusses briefly the technique of how, and reports on what may be in prospect for the future.

WHY IS IT NECESSARY?

Ceylon is a 25,000-sq-mile island, geographically isolated in the Indian Ocean between 6° and 10° north latitude, just off the tip of the mother subcontinent of India. It is a lush and lovely place, richly endowed in natural resources, relatively advanced among oriental states economically and socially, freshly independent politically. Foliage is dense everywhere, from the forests of mahogony and ebony in the mountains, and the rubber and tea plantations of the piedmont, down to the patchwork of paddy fields and jungle on the plains, and the coconut palms fringing the coastal lagoons.

Warm winds and heavy rains characterize Ceylon's climate. Two annual monsoons deposit great volumes of moisture in the high mountains and low jungles. (Incidentally, the word "monsoon" does not imply hurricane or tornado; a monsoon is just a steady rain storm, extremely wet but not necessarily violent.) The Spring monsoon blows in from the ocean on the southwest and spills most of its generous rainfall on the windward slopes of the southwest corner and central highlands of the island. This occurs from April to May when precipitation in this "wet zone" is likely to be from 5 in. to 35 in. a month. The Fall monsoon, less intense, comes from the Bay of Bengal on the northwest and spreads over almost the whole island from September to December when precipitation may vary from 2 in. to 25 in. a month. The seasons are distinguished more by these two periods of rainfall than they are by variations in temperature, which, though uniformly high the year around, are relatively mild for the tropics. In fact, monthly mean temperatures at Colombo vary only 4° during the year, ranging from 77.8°F in December to 81.8° in June.

Ceylon has numerous medium-size rivers and thousands of small streams, most of which are in perennial flow. The mountains of the "wet zone" abound in swift-flowing creeks with white cascades and waterfalls. On the plains of the so-called "dry zone" there also are a number of important streams that are more ephemeral. Some go completely dry from July to September. The notable exception is the Mahaweli Ganga.

Thus, all of Ceylon is rather hot and humid. The three-quarters of the island called the "dry zone" is really dry only in comparison to the extreme humidity of the "wet zone." But, as has been demonstrated, there is maldistribution of rainfall both seasonally and geographically. That is one reason for irrigation.

The other reason is rice. Although Ceylon's three principal cash crops are tea, rubber, and coconuts—all grown without irrigation—the staple of the native's diet is rice. And rice is grown only under irrigation, even during the monsoons. The flooded paddy fields, usually in small plots, dominate most cleared flat lands and many high terraces, some of which are narrowly cut along amazing slopes. Rice culture requires a controlled water supply—an

abnormal duty on Ceylon—of up to 130 in. per crop, including rainfall. That is the second reason for irrigation development on this humid, tropical island.

HOW IT IS DONE

Ingenious irrigation schemes consisting of thousands of storage tanks, which is the common term for small reservoirs, were built in ancient and medieval times by the construction of earth dams or bunds from a few hundred feet to several miles long. In fact, some of the tanks were not small as, for example, Minneriya, built in the 4th century A.D., which has a storage capacity of 110,000 acre-ft. Although most of these ancient tanks had inadequate natural spillways, and, therefore, washed out every now and then, they did have well-designed sluices as irrigation outlets and soundly-engineered distributary channels many miles in length, often linking several tanks into one system to conserve the waters of the wet seasons for use in the paddy fields between the monsoons.

That was in the days of the engineer-kings of ancient Lanka who, by means of irrigation, converted the island's unwatered interior into one of the important granaries of Asia. After about 1200 A.D. irrigation agriculture declined, largely as a result of repeated invasions from the continent by raiders who used elephants to break holes in the earth dams. The water ran out. The jungle soon covered the paddy fields and the reservoirs. Then, complete economic collapse followed malarial epidemics that sprang from the stagnant waters of the destroyed irrigation tanks and channels.

The Government of Ceylon is undertaking (as of 1960) to rebuild these irrigation systems and redevelop the farm lands in the so-called "dry zone" under an ambitious public works program. The Department of Irrigation, in existence since 1900, operates under the Ministry of Lands and Land Development. For many years its work involved, almost exclusively, the rehabilitation or simple extension of old tank schemes. In fact, of 153 operating irrigation projects listed in the Department's 1956 report, only two—Iranimadu, which was completed in 1922, and Gal Oya, completed in 1957—are not restorations of ancient or medieval irrigation works. Some of the more interesting of the redevelopments are worth describing briefly.

Minneriya Tank.—Largest of the old schemes (110,000 acre-ft) it was built by King Mahasen in 327 A.D., partially restored by the British in 1903, and rebuilt by the Department of Irrigation in 1949-54 under a colonization program of the Ministry of Lands and Land Development. The earth bund is $1\frac{1}{2}$ miles long and about 50 ft high. Even this large tank is relatively shallow with a maximum depth of 38 ft. The tank and its left and right bank channels serve 12,000 acres.

Parakrama Tank.—Built during the years 1153 to 1186 by King Parakramabahn, it was restored in 1937-52. The bund is $8\frac{1}{2}$ miles long, located just above the medieval capital of Polonnaruwa. The storage capacity of 98,000 acre-ft serves 18,000 acres.

Minipe Diversion.—Based upon an ancient scheme built about 550 A.D., it consists of a low anicut or weir, 735 ft long, built on the Mahaweli Ganga in 1937-44, plus a left bank channel 18 miles long. The capacity of the old channel is limited to 125 cu ft per sec, serving 3,300 acres of paddy. There is a tentative proposal to re-model the anicut and channel to a diversion

capacity of 1,000 cu ft per sec in order to extend a canal 50 miles further to serve an additional 25,000 acres.

Gal Oya Project.—A modern experiment in national resource development in the nature of a little Tennessee Valley Authority (TVA) has been undertaken in a small river basin of about 700 sq miles on the east coast. It is the Gal Oya Project, started 13 yr ago. The main works are now complete and operating. They include Senanayake Dam, by far the largest in Ceylon, which is an earth fill of 6,000,000 cu yd, 160 ft high and 4,000 ft long, with a 10,000-kilowatt power plant at its base. There is a separate off-channel concrete spillway dam for the 770,000 acre-ft reservoir.

As part of the same system, one other small tank, Ekgal Aru, has been built. A third, Pallang Oya, is under construction. A fourth, Alahena, is started, and several more are contemplated. The left bank main channel, 30 miles long, and its distributary system are complete. The right bank main channel is under construction—both to serve a gross project area of 147,000 acres. Although known as a river valley scheme, the Gal Oya Project is fundamentally a colonization program, involving far more than water resource development. Costs and revenues of the entire program are lumped; there is no separate allocation, for example, to irrigation. According to the Chief Engineer, charges for water, if any, are included in the settlers' rental payments for land, housing, and public improvements. Under this system the economic feasibility of the water and power works is undetermined. Project justification rests on social and political motives.

Mahaweli Basin Project.—An American advisory team of technical assistants is now in Ceylon under the International Cooperation Administration to help the Government plan a larger multi-purpose development on the Mahaweli Ganga. This is the longest river on the island, being 210 miles from its source in the 7,000-ft peaks above Nuwara Ellya to its mouth on the east coast at Trincomalee. Its unique characteristic is that it generates its perennial waters in the highlands of the "wet zone" and brings their freshness to the alluvial plains of its lower reaches in the "dry zone." Affected by both annual monsoons, the Mahaweli has two flood peaks and two low water periods. Obviously, this situation offers intriguing possibilities of comprehensive river basin development. Some of the individual schemes being considered in the Mahaweli basin are the following:

Randenigala Dam.—This is proposed at a site on the main river above Minipe. It would be a concrete gravity dam, perhaps 500 ft high and 3,200 ft long, with a storage capacity of about 3,000,000 acre-ft. Generally considered as the key multi-purpose reservoir in the basin, the site on superficial inspection appears attractive. The foundation is now being drilled.

Polgolla Diversion.—A possible low dam about 10 ft high on the Mahaweli below Kandy would back water up a tributary creek a distance of 3 miles at which point a one-mile tunnel would divert it into the upper basin of the Amban Ganga, a major "dry zone" tributary of the Mahaweli. The purpose of this scheme would be to give the Amban Ganga, which is extremely short of water in relation to its potential of irrigable lands, a perennial supply from both monsoons. Some power development also might be possible.

Victoria Falls.—This is a spectacular cascade in the Mahaweli gorge east of Kandy, which appears subject to easy power development. The natural drop in the river here is 35 ft. A concrete dam might be built above the falls to a height of about 300 ft, to serve a hydroelectric plant just below the falls. Any

water diverted from the Mahaweli by the Polgolla scheme would be lost to the Victoria Falls project.

WHAT IS IN PROSPECT

Population growth in Ceylon since the control of malaria is among the highest on earth, at a rate exceeding $2\frac{1}{2}\%$. The total is now over 9,000,000 people. One result is that Ceylon is no longer self-sufficient in food. The people suffer an embarrassing dependence on other Asian countries, mainly India and Burma, for more than half their daily rice. Almost all manufactured goods also are imported. This shaky economy survives only through large exports of tea, rubber, and coconut, plus some favorable trade in spices, coffee, quinine, and gems. Since much of the "dry zone" is still virgin jungle, one obvious need is for the development of modern irrigation projects to grow more rice and other foodstuffs. The land is there. The water is available. Generally speaking, the technical know-how is there. Irrigation in Ceylon may, fairly, be said to have reached the status of a science. Drainage, however, has not, and that is today's danger.

Irrigation water is not metered. There is no present restriction on its use. Drainage is only a semi-occasional practice. Terraced lands of course tend to drain naturally, but on the flatlands some paddy fields are getting water-logged, resulting in a loss of valuable plant nutrients and sometimes an accumulation of suspended salts and alkalis in the crop root zone. With poor drainage, capillarity and evaporation tend to concentrate these solids at the soil surface. Rice yields in all of the flat areas are decreasing. The average in Ceylon is down to 31 bushels an acre, varying from a low of 20 bushels on many flatland farms to a national high of 70 bushels at Parakrama. Even this maximum yield is low compared to modern rice culture in some other countries. For example, the United States Department of Agriculture reports the following average rice yields for the 5 yr preceding 1958: California, 102 bushels per acre; Japan, 92 bushels; Louisiana, 61 bushels; China, 56 bushels; and Burma, 31 bushels (same as Ceylon).

Thus, a solution to Ceylon's food problem lies not only in bringing more farm land under irrigation, but equally, in the opportunity to increase rice yields by better drainage. No existing project has tile drains accompanying the irrigation laterals. Here and there is an open drainage ditch or a shallow well bailed out by the animal power of the ubiquitous water buffalo. That is the extent of drainage on the irrigated plains.

The Government of Ceylon is alert to these problems and has ambitious ideas of solution. The Minister of Agriculture has announced a goal of more than doubling rice yields to a national average of 70 bushels per acre by better drainage, along with improved cultural practices such as fertilization and weeding. With electricity becoming more widely available, better drainage can be obtained by more pumping from wells. The Director of Irrigation, on the basis of water utilization experiments in the paddy fields, has said that a duty of water of 44 in. to 56 in. is adequate for rice in Ceylon. However, no action has yet been taken to enforce any control (as of 1960). An effort is

being made to promote the growing of irrigated crops other than rice, particularly sugar cane and certain vegetables.

SUMMARY AND CONCLUSION

Ceylon offers an interesting laboratory of humid zone irrigation. The need for it, despite a monsoon climate, has been demonstrated by centuries of practice. The prospect in Ceylon is for more irrigation as part of a national program of comprehensive multi-purpose river basin development. A prime requirement of this program is that controlled irrigation be accomplished by controlled drainage.

APPENDIX. SOURCES OF DATA

General—Report entitled "River Basin Planning for Ceylon," August, 1957, prepared by the author in his capacity as Chief Engineering Advisor, International Cooperation Administration, on assignment in Turkey and Ceylon from 1953 to 1957.

Meteorological—Report on the Colombo Observatory, 1956, published by the Department of Meteorology, of the Ministry of Posts, Broadcasting and Information, Colombo, Ceylon.

Irrigation projects—Reports and publications of the Department of Irrigation, of the Ministry of Lands and Land Development, Colombo, Ceylon.

Rice culture—Reports of the Department of Agriculture, of the Ministry of Agriculture and Food, Colombo, Ceylon.

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CLIMATE AND CROPS IN HUMID AREAS[a]

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SYNOPSIS

Climatic influence must be considered in designing an engineering procedure to increase farm efficiency. Climatic influences that are considered to be of importance in humid areas are discussed herein: (1) the geographical variation of precipitation, temperature, sunlight and day-length, humidity, evaporation and evapotranspiration and their general effect on crops; (2) the microclimate and its effect on crops; (3) climatic influence on the secondary effects of crop production including: diseases, insects, dust and spray operations, tillage and weed control, and fertilization; and (4) specific weather relations of certain crops.

INTRODUCTION

The earliest agriculture in the United States was largely confined to humid regions. Farming was a simple matter of cutting down the forests and planting a crop in the cleared area. Crops were adequate because the soil was fertile, rainfall abundant, and economic pressures small.

Farming today is much different. In many cases the land has been misused and it is necessary to apply special practices to overcome this handicap. In nearly all cases, farming is more competitive and the farmer must take advantage of scientific advances to bring his operation up to a high degree of efficiency.

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Climate affects crop production directly by influencing plant development and indirectly by influencing production practices. An engineering procedure, designed to increase farm efficiency, must take into account these climatic influences.

CLIMATE OF THE HUMID AREA AND ITS EFFECT ON CROPS

The problem of climate's influence on crops is similar to most engineering endeavors, in that the climate must be measured in precise enough terms to determine its effect on crops, and yet stay in the realm of practicality. In this attempt, the general subjects precipitation, temperature, sunlight and day-length, humidity, evaporation, and evapotranspiration will be considered. (Data for particular cities or areas may be found in the United States weather bureau (USWB) publication "Climatological Data" available at most Weather Bureau offices.) A number of other climatic variables influence crop growth, however, these six are considered of primary importance. (Storm damage is an infrequent but important weather variable. Each year severe storms ruin crops in local areas, however as there is little or no control over this possibility, storm damage will not be considered in this report.)

For most agricultural purposes, the basic classification of climate is moisture distribution and the only measure of this distribution with a long period of record is rainfall. Many research works define a humid climate as one with over 30 in. of annual precipitation. Fig. 1 shows this classification includes most of the eastern third of the contiguous United States with scattered areas in the Far West (1).[3] To simplify the discussion, and to make the classification along familiar geographical lines, this paper will consider the humid areas to be: Minnesota, Iowa, eastern Kansas, eastern Oklahoma, eastern Texas and all the states to the east; also western Washington, western Oregon, and northern California.

Precipitation.—The largest average yearly precipitation amounts, as shown by Fig. 1, occur along the Pacific northwest coast and along the Gulf coast. In the northwest, precipitation drops off sharply 100 to 200 mi inland. Over the eastern half of the country, the decrease in precipitation away from the Gulf is much more gradual. Fig. 2 shows another measure of moisture distribution, the annual number of days with 0.01 in. of moisture or more (1). This distribution gives quite a different picture as to which areas are moist. For example, upper Michigan, which has only about 30 in. of annual precipitation, has approximately 160 days on which 0.01 in. of moisture is recorded.

The seasonal variation in precipitation is probably more important to agriculture than the total amount. The northcentral states have a summer maximum while a spring maximum is general in the South except along the east coast where a fall maximum reflects the infrequent but heavy rains of hurricanes. The northeastern states have very little season variation. Along the west coast, precipitation has a very strong winter maximum, quite different than the rest of the humid area.

Even after the precipitation distribution has been determined for a region by a system of averages, only part of the variation is known. Fig. 3 shows the average yearly precipitation for the driest 10 yr out of 40 (1). Compared

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[3] Numerals in parenthesis—Thus; (1)—refer to corresponding items in the Appendix.

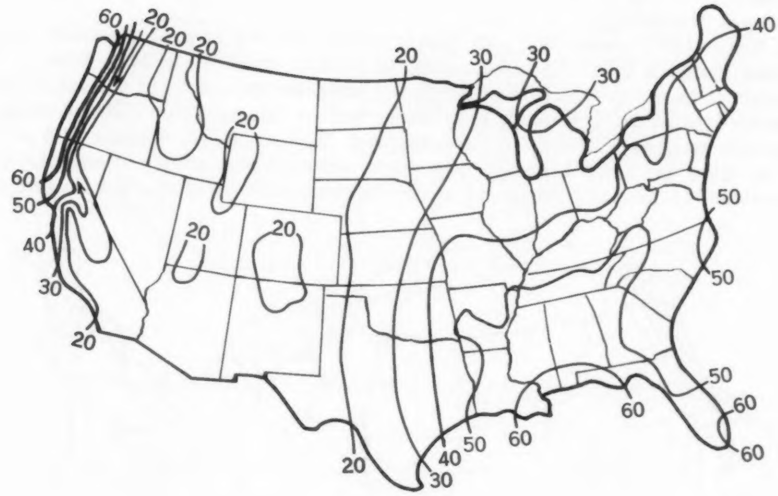

FIG. 1.—AVERAGE ANNUAL PRECIPITATION

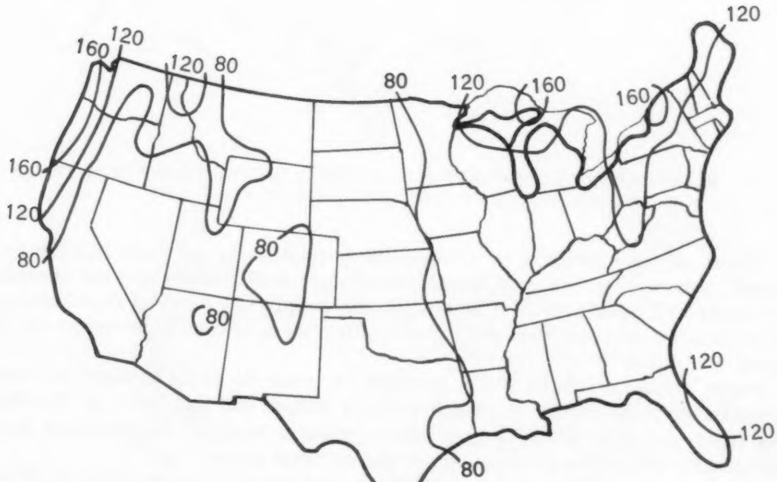

FIG. 2.—AVERAGE ANNUAL NUMBER OF DAYS WITH PRECIPITATION OF 0.01 IN. OR MORE

with Fig. 1, the area with 30 in. of annual precipitation is much smaller. When shorter periods of time are considered, even this wet area experiences significant droughts (2).

Very heavy rains that fall during short periods of time are most likely along the Gulf coast. Rainfall amounts of 12 in. to 15 in. in 24 hr have a reoccurrence interval of 100 yr along the coast and inland about 100 mi. These heavy downpours are much less likely further inland. From eastern Kansas through northern Illinois to New England, 24-hr rainfall amounts of 5 in. to 7 in. have the same reoccurrence value, whereas in northern Minnesota, the heaviest 24-hr rain likely to occur once in 100 yr drops to 4 in. to 5 in.

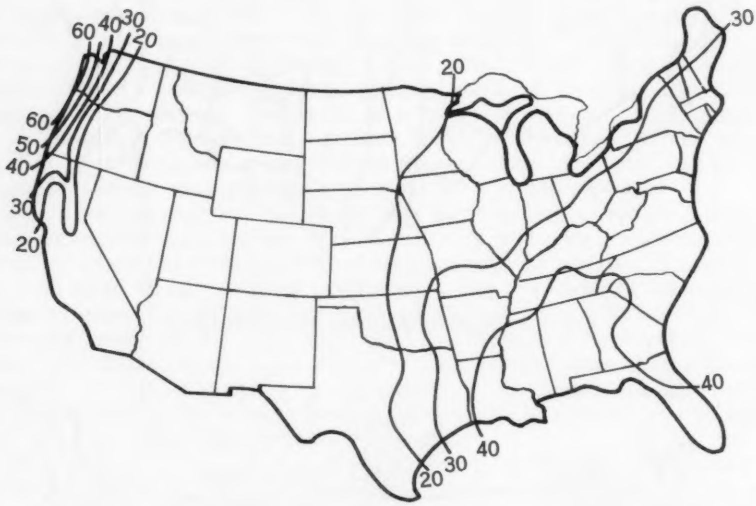

FIG. 3.—AVERAGE PRECIPITATION FOR THE 10 DRIEST YEARS IN 40 YEARS

Effect of Precipitation on Crops.—Precipitation is not essential for crop growth, however, an adequate supply of moisture is necessary and the cheapest and most common method of achieving this supply is by way of precipitation. More information on crop moisture requirements is found elsewhere in this paper.

Heavy local rains in short periods of time do great damage to crops. Directly, they can injure the crop by beating it down and indirectly by flooding. The flood potential of some crop land is greater than the rest because many high quality crops are grown near rivers on flood plains.

Temperature.—Temperature is the second major climatic classification. Fig. 4 shows the average date of the last 32° temperature in spring (3). Fig. 5 shows the average length of the growing season as determined by the interval between the average date of the last 32° temperature in spring and the first 32° temperature in fall. In the eastern humid region, the growing season de-

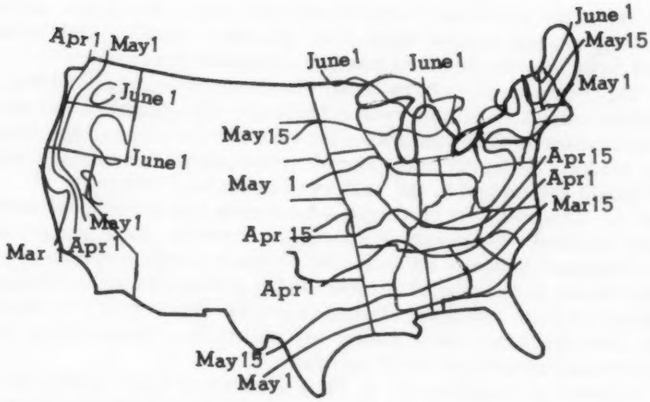

FIG. 4.—AVERAGE DATE OF LAST 32°F TEMPERATURE IN SPRING

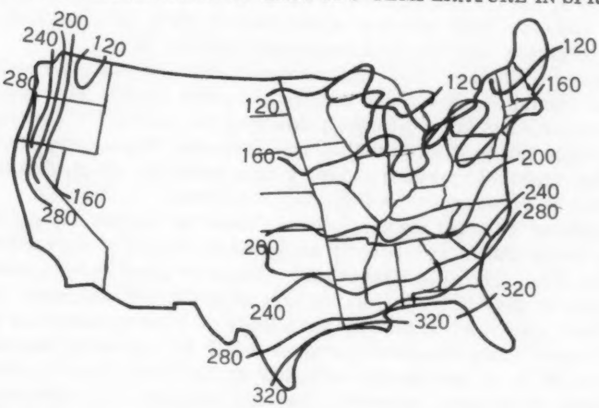

FIG. 5.—AVERAGE LENGTH OF GROWING SEASON

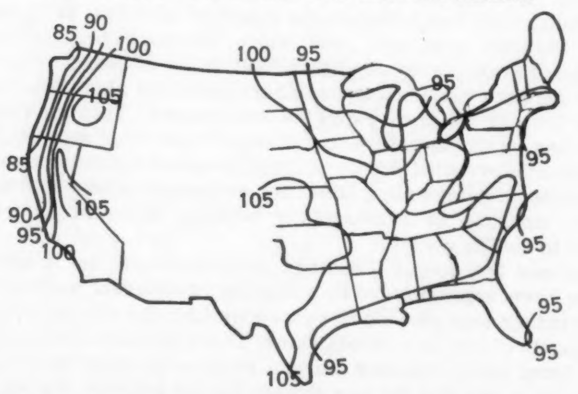

FIG. 6.—AVERAGE ANNUAL MAXIMUM TEMPERATURE (°F)

creases from the southeast to northwest with minor increases around lakes. The growing season ranges from over 300 days along the Gulf coast to only about 100 days in some sections near the Canadian border.

Very high temperatures have lethal effects on some crops and Fig. 6 shows the average annual maximum temperature (1). The geographical variation of high temperature is very much smaller than the variation of the length of the growing season. Highest temperatures occur along the western edge of the eastern humid region and in the valleys of northern California.

Effect of Temperature on Crops.—Each crop has its own optimum, maximum and minimum temperature standards, however, most crops make their best development between 60°F and 90°F. Many plants make no growth when the temperature is down to 40°F whereas an extreme case, sorghum, practically stops growth when the temperature is down to 60°F. Depending on maturity and condition, most plants are killed by a temperature of 32°F or lower, and many others by 100°F or over.

The relation of temperature to crop production has evolved into two frequently quoted laws. According to A. D. Hopkin's Bioclimatic Law; starting in the sourthwest part of the country, such events as seeding time are generally delayed 4 days by each advance of one degree north latitude, five degrees of eastward longitude, and 400 ft of increased altitude (4).

Vant Hoff-Arrhenius' law for monomolecular chemical reactions holds true within normal temperature ranges and plant growth increases with each rise in temperature, approximately doubling for each 10°C increase. An extension of this law makes possible the "growing degree day" that is widely used by the vegetable packing industry as a guide for all phases of operation from the day of seedling to the final day of harvest.

The engineer has, for many years, utilized the degree day for heating requirement study and more recently as a measurement of air conditioning requirements. The "growing degree day" theory of plant development replaces growing time in days by accumulated heat units (5). For example, the pea is a cool weather plant and peas will germinate at a temperature of 40°F. Each degree of mean daily temperature over 40°F is a growing degree day. For sweet corn, 50°F is commonly accepted as the base. Variety requirements for the same crop vary, however, they are less than the difference between different crops. In the state of Wisconsin, the heat requirement for maturity varies from 1250 degree days for Alaskan peas to 1775 for Perfection peas. Some of the factors that influence the range of total heat units required for a crop or a variety are; soil type, slope, drainage, fertility level, depth of planting, spacing of plants, droughts, and vigor of seeds. The difference in day-length between northern and southern locations also influences the total, the longer the day the more rapid the development. This growing degree day procedure has great advantage to the user. It provides an effective basis for planning an uninterrupted supply of fresh crops at optimum maturity. It provides a means of determining labor and equipment needs. For the grower, it provides a measure of performance between different varieties and is a definite aid in quality control.

Sunlight and Day-length.—Sunlight measurement, as it affects growing plants, has been approximated by a number of different methods. USWB stations have rather long periods of record showing the average number of days of clear, partly cloudy and cloudy skies. There is a somewhat shorter period of record from many Weather Bureau stations showing the average percent of the daylight hours that the sun shines, for the average, during the summer months (Fig. 7) (1).

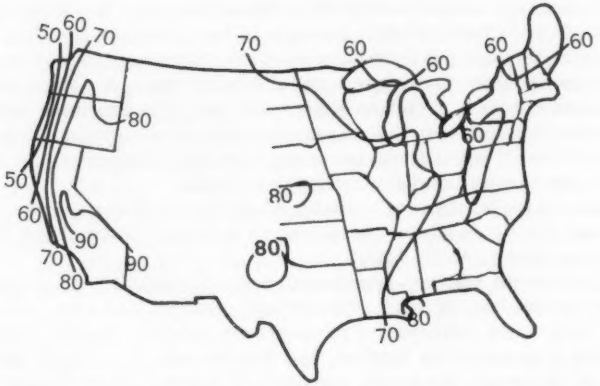

FIG. 7.—PERCENTAGE OF POSSIBLE SUNSHINE, SUMMER (JUNE-AUGUST)

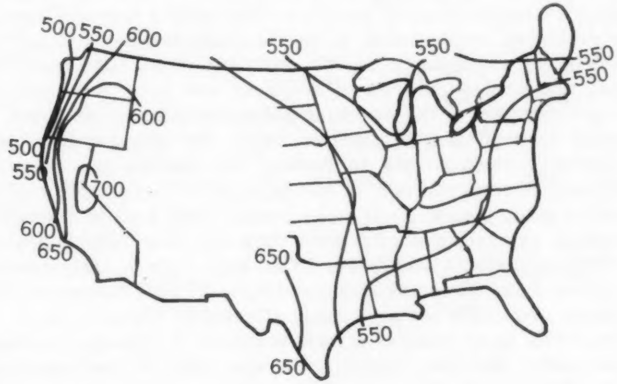

FIG. 8.—AVERAGE JULY SOLAR RADIATION, LANGLEYS PER DAY

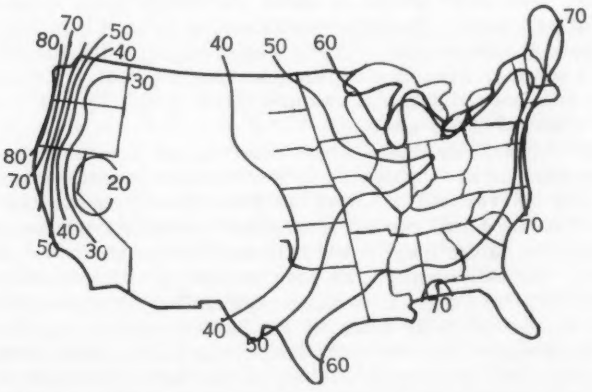

FIG. 9.—AVERAGE RELATIVE HUMIDITY, LOCAL NOON, JULY

A more precise measurement of sunshine intensity is shown in Fig. 8 (6). It gives the 5-yr solar radiation average in Langleys per day for July for the period of 1953 through 1957. (A Langley is one gram calorie per square centimeter). More recently, measurements are being made of net radiation, which is the earth's outgoing radiation subtracted from the incoming radiation. Net radiation has the greatest use in plant growth determination, however it has great variability. It not only varies with geographical location, but in the same area, it varies because of different ground cover.

Day-length is a function of latitude. Along the northern border, day-length ranges from 8.2 hr in winter to 16.1 hr in summer. In southern Florida, the range is from 10.6 hr to 13.7 hr.

Effect of Sunlight and Day-length on Crops.—Sunlight affects photosynthesis, the plant's production of food. Insufficient sunlight has a detrimental effect on crops. Too much sunlight for plant growth seldom, if ever, occurs except in cases where moisture is limited, and then the excess sunlight dehydrates a plant. Often, however, the bright sunshine of midday is not fully utilized by a plant and that percent of sunlight above a certain threshold is wasted.

The full potential of the greater amount of sunlight in the South offers opportunity for improved farm practice. One method that has been practiced is double cropping. Oats seeded in the fall and harvested in the spring are often followed by sorghum, corn, or soybeans. Oats have declined in their cash value, and double cuttings of sorghum are being tried as a method of utilizing a greater part of the incoming solar radiation in the South.

Day-length is important in plant maturity. The long summer days at high latitudes cause certain plants to develop and mature in a relatively short period of time. Photoperiodism is the process of day-length's effect on the life process of many plants. Some crops require long days to produce flowers, but increase in vegetative growth when days are short. Small grains, except rice, are long-day plants and flower in the long days of early summer. Soybeans generally delay flowering and maturity until days become short. Cotton and some other crops are not materially affected by this process.

Humidity.—The most commonly used measure of atmospheric moisture is relative humidity. Relative humidity is the ratio of the actual amount of moisture in the air to the amount of moisture that the air could hold if it were saturated. Fig. 9 shows the average noon July relative humidity (1). It is highest near large bodies of water and lowest in the large continental land mass of the country. Temperature influences relative humidity; warm air can hold more moisture than cold air. For example, if the relative humidity is 100% on a summer morning with a temperature of 65°, it will drop to around 40% in the afternoon if the temperature rises to 95°. This is accomplished without the removal of any moisture.

Wet-bulb temperature is a more conservative measure of moisture if temperature changes are involved. The wet-bulb temperature is the temperature that will be reached if water is evaporated from the bulb of a thermometer. When the actual content of atmospheric moisture is needed instead of an estimate of saturation, the wet bulb should be used instead of the relative humidity. Wet bulb temperature does not have the diurnal fluctuation that relative humidity has, also, it is more regular in geographical distribution. In contrast to the irregular lines on Fig. 9, the average July noon relative humidity, the average July wet bulb temperature decreases gradually from 75°F along the Gulf coast to 60°F along the northern border. In the western humid area, the average July wet-bulb temperature is 55°F to 60°F.

Effect of Humidity on Crops.—Humidity's effect on crop growth is mainly indirect. High humidity limits evaporation and transpiration and is quite helpful when the moisture supply is critical. High humidity, accompanied by clear skies and light winds at night is associated with heavy dew formation. Some researchers have found that the addition of dew is a significant addition to the moisture supply (7). High humidity promotes many plant diseases and has a lesser affect in promoting certain types of insects.

Evaporation and Evapotranspiration.—Evaporation increases with increases in temperature, sunshine, and wind, and with decreases in relative humidity or wet-bulb temperature. Various types of pans and porous cups have been used in an attempt to measure this variable weather element, but none gives results satisfactory to all researchers. Fig. 10 shows the average annual

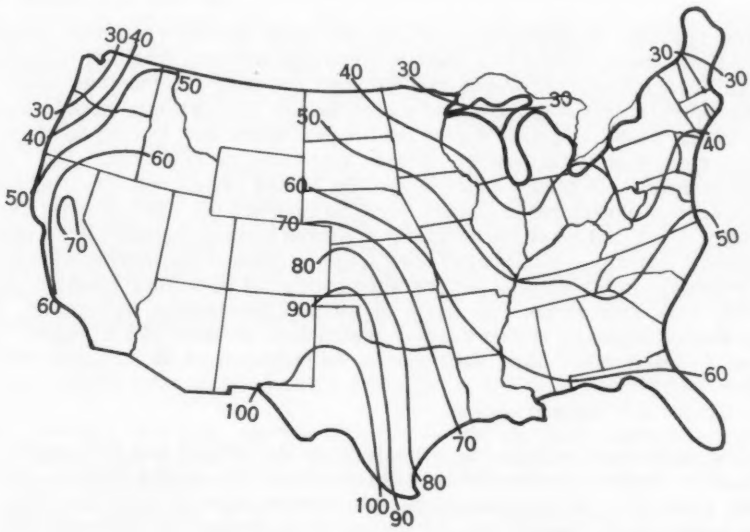

FIG. 10.—AVERAGE ANNUAL CLASS A PAN EVAPORATION IN INCHES (1946-1955) WEATHER BUREAU TECHNICAL PAPER NO. 37

evaporation as determined from the USWB class A pan (8). Highest values of evaporation are found in the warm, drier, southwest part of the humid region, decreasing to the north and east in the cooler and moister areas.

Evapotranspiration is the total moisture loss due to evaporation from the soil, and transpiration plus evaporation from plants. Various methods have been designed to estimate evapotranspiration utilizing records of other weather elements. One of the simplest and probably the most widely used is the C. W. Thornthwaite method that makes use of mean temperature and day-length (9). The N. L. Penman method utilizes more complete weather records and is restricted to areas where measurements of wind, humidity, and sunshine are available (10).

Effect of Evaporation and Evapotranspiration on Crops.—Computations of evapotranspiration may be used as an indication of moisture needs for maxi-

mum plant growth and thus serve as a basis for an irrigation program. The computed moisture requirements are more applicable when total plant growth is measured. They are less applicable when the fruit of a plant is to be harvested, especially if a balance between plant growth and fruiting is necessary for maximum fruit set and maturation. In most of the humid areas, the driest weather in the growing season is usually the hottest weather. Because of this and other interrelationships of weather elements, the consideration of rainfall fluctuations may give results similar to the more detailed formula methods for computing moisture deficits. Regardless of the method of computing moisture deficits and irrigation needs, there is no complete substitute for an intimate knowledge of the plant's response to a moisture deficiency.

MICROCLIMATE AND ITS EFFECT ON CROPS

The climate, as discussed thus far, has been the macroclimate. Plants, insects, and diseases live in a climate somewhat different than that measured by an instrument 5 ft above the ground, and their life functions must be studied in relation to their true, or microclimate. For example, many insects stay in the shade of plants during the hot part of the day. During the dead of winter, most insects that survive stay in the protection of debris.

To measure the micro-weather for the United States with the frequency that macro-observations are made would be impractical. Thus, temperature, humidity, wind, and other observations are taken at some standard level above the ground and with a minimum of obstruction to sun and air movement. These macro-observations show a pattern when compared with other readings over a wide area that forms the basis of weather forecasting. Frequently, the temperature readings at two regular instrument shelters 500 mi apart, are closer to each other than they are to the temperature 50 in. below either shelter.

R. Geiger (11) sums it up thus:

> "The difference between the climate near the ground and the macroclimate consists essentially in the proximity of the earth's surface. As the lower limit of the atmosphere, this surface plays an important role in meteorology. The heating and cooling of the atmosphere in the course of the day and according to seasons, takes place in general through it as an intermediary. By evaporation from it, water vapor is given to the air—returning to it again as rain and snow. It acts as a brake on the winds which pressure differences initiate. It is therefore no wonder that the ground air layer shows peculiar climatic characteristics."

> "But there is something more. While, in the upper air contrasting conditions which occur are immediately equalized; in the air near the ground they may continue to exist almost side by side, for every convective movement which is initiated is tied up by friction on the surface. Horizontal contrasts are added to vertical. Great climatic differences can result within the shortest distances by reason of the kind of soil, its form, the plants growing thereon, variable shading or sunniness, different wind protection, and many other circumstances."

The effect of plants in changing the adjacent climate is very great. Relative humidity has a direct effect on cotton value at harvest time. In the fall of 1959, measurements were made in the Mississippi Delta of the microclimate

in a cotton field that was heavy leafed and in one with very little leaf cover. The relative humidity averaged almost 9% less in the defoliated field during the driest part of the afternoon (12). Evaporation in the heavy leafed field was only half as much as the defoliated field.

Examples of the difference in micro versus macroclimate are endless. The important thing to realize is that there is a difference and then determine what the difference is for each case under consideration.

Although irrigation is the most common method of changing the microclimate there are other practical methods. Mulching the ground around crops for moisture conservation and soil temperature control has been done in some humid areas. Frost protection is the most spectacular effort in controlling microclimate and varies all the way from flooding the cranberry bogs, burning oils, and blowing the air around with giant fans to burying vegetable crops temporarily with soil.

Shelter belts have been widely used in the more arid regions but also have use in the humid area. The reason for the belt is to reduce air flow in the protected area, thereby decreasing evaporation and transpiration. It also has minor effects on temperature and increasing effective precipitation. The net result of all factors contributes to increased yields of certain crops and a reduction of wind damage.

The principle of the shelter belt is to break large eddies into small ones, thus decreasing the wind speed. A belt with about 50% permeability will do this most efficiently, a belt that is solid merely lifts the air current over the barrier and then returns it to the ground a short distance to the leeward. A belt of 50% permeability will reduce the wind speed by 20% over an area from 2 times its height on the windward side to 15 to 20 times its height on the leeward. A lesser reduction extends even further.

CLIMATE AND SECONDARY EFFECTS OF CROP PRODUCTION

The weather not only affects crops directly, as previously stated, but affects production indirectly by influencing crop diseases, crop insects, and many production practices.

Diseases.—According to P. R. Miller, "Given a susceptible plant, the area of occurrence of a plant disease depends primarily on climate" (13).

Plant diseases are caused by fungi, bacteria, and viruses. They are soil-borne, air-borne, and insect-borne. All of these are affected by different combinations of weather.

Many diseases need a good deal of moisture and thus favor the humid region. Cotton anthracnose stays east of a line in east Texas and Oklahoma that corresponds to the 10-in. average summer rainfall. It is a constant and important disease in the humid eastern cotton belt, but is almost non-existant in drier western sections. Apple scab is favored by a cool wet spring and is a humid area disease.

Several important soil-borne organisms cannot stand low temperatures for long. Some of these are Granville wilt of tobacco, southern blight and the Texas root rot of cotton. All attack many kinds of plants and are practically confined to the South. Potato late blight is favored by cool wet weather, however it is not restricted to the North because southern potatoes are grown in the cool moist winter and spring months.

The spread of a plant disease follows a cycle. The plant is infected, the disease grows within the plant tissues, it reproduces and reinfects the plant, and finally it goes into a carry-over stage. All of these stages are affected by weather. The overwintering stage often subjects the disease to its greatest exposure, however, by moving into the soil or debris, or by conversion to a more hardy form, the disease avoids the lethal weather. Certain rusts of wheat overwinter in the South and must then find their way back the next year in spore form by riding the high wind currents. Weather helps spread many diseases by wind and rain, and some soil-borne fungi are spread upward on a plant by the splashing of raindrops.

The weather disease relationship is a complex one and is frequently complicated further by the effect of weather on the disease host. In general, the climate of the humid region favors the developments of many crop diseases.

Insects.—The level of production of many crops is often determined by insects. Weather, directly or indirectly, is the greatest single factor that affects insect populations. It influences the type of insects that live in an area, the numbers, and the seasonal occurrence of the different stages of the life cycle.

The very closeness of the weather-insect relationship is largely due to the fact that insects are "cold-blooded" and respond directly to temperature changes. Most insects thrive in the relatively narrow temperature range that approximates the range of human comfort. Few insects are active above 120° F or below 40°F. Many insects are killed by freezing weather while others survive winter freezes only in a particular stage of their life cycle. For example, the gypsy moth survives the winter as an egg, the brown tail moth as a larva, the tomato hornworm as a pupa, and the chinch bug as an adult. The temperature effect ranges from lethal to optimum with an intermediate zone in which many insects are reduced to a dormant stage.

The time required for various stages of the life cycle of many insects is a direct function of temperature. Within the temperature range of greatest insect activity, there is usually a shorter time necessary for completion of a life cycle. For example, Isley in Arkansas found that the boll weevil developed from egg to adult at 88°F in half the time required at 70°F.

Some insects rely on wind to avoid the winter attrition. The cotton leaf worm, a tropical insect, winters almost entirely south of the United States. As the growing season develops, it moves farther north with each new generation. In the fall, adults appear in the northern states and even in Canada. Winter destroys all stages of this insect in the North and its reappearance is dependent on its spring migration. Corn earworms usually cannot survive northern winters, so they pass the cold season in the South and move northward as moths, later to develop a new generation of larvae that feed on northern tomatoes and corn.

In addition to relying on wind for survival, many insects are dependent on wind and air currents for their spread. Great numbers of insects travel through the air and some move great distances. They are generally concentrated in the lower levels, however, the cotton aphid has been trapped at 13,000 ft and a number of very small insects at 15,000 ft. In sunny warm weather, the air near the ground is subjected to intense heat in the middle of the day. This causes strong updrafts to occur and insects are carried high into the air. After they attain a certain altitude, they are carried along by the prevailing upper winds. Wind direction varies, however, in the eastern humid area, winds from the south or southwest usually accompany conditions favorable for updrafts.

Moisture affects insects indirectly by promoting succulent plant growth, thus providing an abundant supply of food. This is perhaps the main reason insects thrive in the humid area. However, it is true that most insects need a minimum amount of moisture to avoid desiccation, and some insects are dependent on rain puddles for reproduction. On the other hand, very heavy rain is often harmful to insects. It sometimes washes them off the plants on which they are feeding, or drowns some that are in the more sensitive life stages. Some forms of grasshoppers are limited by humid weather which favors the growth of destructive fungi that feed upon them.

Cotton, due to its long field life, has its full share of insects. The following are some of the typical weather insect relations. Cotton boll weevil is limited by low winter temperatures and hot dry summers. During winter, a series of freezes and thaws is more destructive to the weevil and many other types of insects than is extremely cold weather. During the warm thaw period, some of the insects leave their shelter and if a freeze comes with enough suddenness, many are destroyed. Cotton aphids are favored by cool damp weather. The cotton fleahopper is favored by rain and will continue breeding on cotton as long as leaves are succulent. Spider mites, another cotton belt pest thrives in hot, dry weather while a heavy rain often checks an outbreak.

All insects are greatly influenced by weather and all have certain optimum degrees of temperature and moisture, beyond that, generalization is impossible except to note that a great many insects find the humid area the best home. Unfortunately, as with diseases, many insects have optimum weather conditions somewhat similar to the crops upon which they feed and this makes scientific control essential for agricultural efficiency.

Weather for Spraying and Dusting.—Application of dusts and sprays is a necessary part of scientific agriculture in the humid area. These materials may be applied for insect control, disease control, weed control, or as a pre-harvest measure. Whatever their purpose, weather influences their application and their efficiency. Moisture, wind, and temperature singly, or in combination, will largely determine the effect of dust and spray treatments. The choice between a dust and a spray may be dictated by weather conditions.

During the day, the sun warms the soil faster than it does the air just above the ground level. This causes convection currents. These rising columns of warm air are most frequent and reach their highest velocities just after noon on a sunny day. At this time, air tends to be stirred the greatest and a dust or spray treatment has the poorest chance of reaching its target. Sprays provide considerably more leeway in this respect than dusts. Air movement is usually least in early morning hours and late afternoon hours. Exceptions occur when a front or a strong pressure system moves through an area.

Wind velocity is a key factor in determining whether a dust or spray may be applied satisfactorily. Wind speeds in excess of 8 mph to 10 mph will cause considerable drift of dusts, and to a lesser degree, sprays. The drifting materials will be less efficient to the crops intended for treatment and may even produce harmful effects on adjacent crops. This is especially true with some herbicidal materials in which drifts have caused damage to crops more than a mile from the treated areas.

In addition to requiring calm weather conditions, most of the dusts also require dew to be effective. The application of harvest-aid dusts is a notable example. Where these materials are to be applied, the crop producers have come to depend on the dew forecast in making plans for treatments.

Wind and dew influence the application of sprays and dusts, but in most cases, rain determines the degree and length of effect of treatments. Rain immediately after application of dusts or spray will reduce the treatment's effect, and depending on the amount of rainfall, may render the treatment completely ineffective.

Temperature is an important consideration in selection of chemicals to be used as dusts or sprays. In insect control, some chemicals break down rapidly at high temperatures, and are effective for only very short periods, whereas others are effective only at high temperatures. Low temperatures generally reduce the activity of harvest-aid chemicals. Since some chemicals can tolerate lower temperature than others, the selection of the material will be influenced by prevailing and anticipated temperatures.

Tillage and Weed Control.—The threefold purpose of soil tillage is to improve soil structure, prepare a seed-bed, and to control weeds. Humid conditions make it difficult to achieve the second and third objectives without having adverse effects on soil structure. Tillage of the soil when the moisture content is high may cause soil compaction. Excessive tillage of rolling land, especially when no immediate cover is to be provided, will promote serious erosion.

In recent years, the use of chemicals for weed control has expanded rapidly. This practice is even more dependent on climate than mechanical methods of weed control. Moisture is required to activate the chemicals, but heavy rains may cause them to be lost. Low temperatures may prevent the chemicals from having any effect on weeds, while high temperatures may cause the effect to be short-lived.

In general, weather conditions that favor crop production, encourages weed growth and, at the same time, makes control measures difficult.

Fertilization.—Crop fertilization is necessary in most humid areas for economic yields. For many years fertilization was practiced only in the humid areas and, as late as 1950, 95% of the commercial fertilizer was used in the eastern half of the nation. Without considering indirect relations between fertilization and climate, there are several in which climate exerts a direct influence on crop fertilization programs. Without elaboration a few of these relations follow:

1. Moisture is necessary for the plant utilization of commercial fertilizers.
2. High rainfall and high temperatures promote rapid decomposition of organic matter. Thus, in the warmer portion of the humid area, climatic conditions prevent a build-up of organic matter and soil nitrogen. The rate of activity of soil micro-organisms above 45°F increases two to three times for each 18° rise in temperature if moisture is adequate and the soil is not highly acid.
3. Rainfall causes soil nutrients to be leached from the soil. The greater the rainfall and the coarser the soil texture, the greater will be the nutrient loss.
4. Loss of soil bases by leaching due to heavy rains increases soil acidity. This may result in a need for a liming program.
5. Extended periods of wet weather with high temperatures on fine textured soils may cause loss of nitrogen by denitrification.

Because of the temperature difference within the humid area, two greatly different fertilizer programs may be applicable. In the areas with lower

temperatures, it may be practical to fertilize the soil. In the warmer areas, the crops should be fertilized rather than the soil.

WEATHER RELATIONS OF CERTAIN CROPS

Cotton.—Three climatic factors localize the area of cotton production: a long frost-free growing season, a large supply of moisture, and a plentiful amount of sunshine. Plant variety and management practices have succeeded in modifying the requirements slightly, however, cotton requires a frost-free season of about 180 to 220 days, an optimum supply of 20 to 28 in. during the growing season, and sunshine during over half of the daylight growing period.

Soil temperature should reach an average of 70° for optimum seedling emergence although germination requirements are slightly less, and a practical average for planting is about 65°. Soil moisture must be adequate to germinate the seed, or showers must occur in a week or so after seeding. Frost occasionally kills the plants and necessitates replanting especially in the northern part of the cotton belt, however, cool wet weather that promotes seedling diseases is more often the limiting factor.

Cotton's very long period in the field subjects it to all types of weather damage. Winds and hail do physical damage, very heavy rains sometimes cause flooding, and the weather is usually favorable to many insects and diseases. Cotton fruits over a long period of time. Most crops are especially sensitive to moisture deficiencies and excesses during the fruiting period. So it is with cotton, and this spreads the sensitive time over a period of months, not weeks or days.

During the summer, a well distributed rainfall is desirable. Frequent changes from cool-and-damp to hot-and-dry causes a shedding or dropping of bolls. A deficit of sunshine also causes shedding, as do a number of other adverse weather conditions.

During the harvest, cotton continues sensitive to weather. Temperatures of freezing or much below cause bolls to rot. A light frost causes the leaves to drop and is beneficial to the harvest. Chemical defoliation is common in humid regions. It disposes of the leaves and mechanical pickers gather a smaller percentage of trash. When cotton is picked wetter than about 10% moisture content, the various quality measures suffer. Measurements made in defoliated cotton show that "safe" picking time is increased about a hour, due to the drier microclimate that prevails in daytime in humid areas.

Corn.—Because of its adaptability, corn is grown successfully in every state of the country and at altitudes from sea level to 10,000 ft, however, it is concentrated in the middle of the country, in the corn belt. Corn is a warm weather crop, and the corn belt with a mean summer temperature of 70° to 80° and a frost-free period of 140 days suite it well. Warm nighttime temperatures are important, and in this region the average summer minimum is over 58°.

The minimum temperature for germination of most corn varieties is 50°, and very little growth is made after the plant is up when the temperature is below that level. Prolonged temperatures of below 45° will kill many varieties of corn. Most plants will stand a light freeze in the seedling stage, but after that, a freeze will kill all but the most hardy plants.

Corn flowers and ripens much sooner when grown at 80° than at 70°, and temperatures as low as 60° greatly retard maturity. Extremely hot weather

may injure the plant, especially when combined with deficient moisture. The time of tasseling is a most sensitive period.

The best corn regions have an annual rainfall of 25 in. to 40 in., except for areas of irrigation. The moisture required during the growing season for optimum production varies from 20 in. to 28 in. depending on soil type, variety, temperature, and evaporation conditions. The critical period is during the three weeks following the initial show of tassels.

Extended periods of cloudiness harm corn, which requires abundant sunshine. At the time of harvest, sunshine and open weather are needed to bring the moisture content down to a safe level for storage. Corn is usually picked with a moisture content of 13% to 30% moisture. To be safe in storage bins, it should contain less than 15% moisture. When the first freeze catches corn in an immature state, and with a high moisture content, "soft" corn results. This is unsuitable for processing, and the best use of soft corn is prompt feeding to avoid spoilage.

Corn is a short-day plant, flowering is speeded and vegetative growth slowed by short days. Varieties that have been developed for a particular area suffer by the change of day-length when they are moved either north or south.

Thunderstorms, wind and hail storms have a relative high frequency in the corn belt, and at times cause considerable damage. The mechanical picker emphasizes the problem of broken stalks such that the ears cannot be reached. The European corn borer often attacks stalks, weakening them and making them further susceptible to wind damage.

Sorghum.—Weather requirements as well as uses of sorghum are similar to corn with some major differences. Sorghum seems to tolerate extreme heat and drought better than most crops, however, extremely high temperatures during the fruiting period does reduce seed yield. The most favorable mean temperature is about 80°F. The minimum temperature for growth is about 60°F. It is a short-day plant.

Sorghum does well with limited rainfall, but is highly productive in humid and irrigated areas. The plant has more secondary roots than corn and smaller leaf area. Also, the leaves and stalk wilt and dry more slowly than those of corn; a waxy cuticle seems to slow drying. Sorghum plants remain dormant during drought, but begin again after sufficient rain. Its resistance to heat, drought, and certain insects make it adaptable in some areas where corn is not. A number of economic qualities make it secondary to corn in most areas. In the Mississippi Delta, land efficiency is being increased by harvesting a double crop; one in the spring or early summer with a head chopper, and another head crop or the entire plant again in fall. This double cropping is especially desirable in high-value land.

Small Grains.—Wheat production is not as extensive in the humid regions as in the dry plains states. Excessive moisture, especially when combined with high temperatures, favors the diseases of wheat. Heavy rains cause lodging or breaking of supporting straw. General wet weather at harvest time is quite detrimental. Soft red winter wheat varieties are general in the humid wheat states. These are planted in the fall and must pass through the winter cold.

The Hessian fly is a serious pest of wheat, particularly in the humid East. To minimize damage by this pest, the fall planting date is established late enough that the main brood of flies will have emerged and died before the

young plants appear above the ground. The "fly-free dates of planting" are well established in the humid region and are well adhered to. A number of other insects and diseases also attack wheat in humid areas.

Most oats are best adapted to cool regions with an annual moisture supply of 30 in. or more. Hot, dry weather is detrimental during most of the life of oats, although some varieties are more tolerant than others. At time of heading and ripening, hot, dry weather causes premature ripening and the grain is poorly filled. Lodging is a serious problem in most sections and wind can do considerable damage to oats.

Rice requires considerable heat and moisture. A mean temperature of about 70°F is necessary for the long growing season of 4 to 6 months. A constant supply of fresh water for irrigation must be available. In the South, rice is usually submerged from the time the seedlings are 6 in. to 10 in. high until just before the harvest. The land is flooded to a depth of 1 in. to 2 in. at first, and gradually increased to 4 in. to 6 in. through the summer. The water requirement ranges from 24 in. to 48 in. The time of submergence averages 3 to 5 months in the South while in California the time of submergence is a little longer. Even for rice, however, a period of open weather at harvest time is necessary. If the open weather is accompanied by an abundance of sun and hot, drying winds, the grain is subject to cracking.

Legumes.—Soybeans have climatic requirements quite similar to corn, and in fact, the corn belt is the most concentrated soybean area. Germination is the most sensitive period in soybean growing; either drought or weather that is too wet is harmful. Soybeans are somewhat less susceptible to frost injury than is corn, and light frosts are not injurious to either young or mature soybeans. The plant will survive a short period of drought after it is established, but a water shortage brought on by the combination of hot and dry weather is one of soybeans' worst threats. High temperatures alone will lower yield and quality of oil. The soybean is a short-day plant and thus matures in the shorter days in fall, and in the South, can be harvested in time to plant a fall oat crop.

Alfalfa, while adapted to widely different climatic conditions, makes its best growth in the sub-humid areas, but where irrigation is available. In areas of irrigation, good drainage is essential. It can stand extremes of heat and cold. It can stand long periods of drought, but it grows very little and merely sustains its life. The growing of alfalfa has increased in the last 10 yr to 20 yr (since about 1940) because of increased knowledge of fertilizer requirements.

Sweetclover is also adapted to a wide range of climates, and is grown in every state although its greatest concentration is in the great plains, and the north-central states. Sweetclover is grown in areas where spring and summer rainfall is 15 in. to 20 in. or more. It survives drought similar to alfalfa, however, moisture and cool temperatures are necessary for germination and early seedling growth.

Red clover is widely grown in the cooler humid parts of the country for soil improvement and forage. Rainfall appears to be the main limiting climatic factor in the northern part of the humid area, however, the cold temperatures of winter occasionally kill a stand. High summer temperatures do not injure the plant except in connection with a water shortage. Alsike clover requires a cool climate with ample moisture; it withstands severe winters better than red clover. White clover grows best in moist, cool weather and will with-

stand extremes in temperature better than either red clover or Alsike clover. White clover is grown in the southeast as a winter annual and dies in the early summer after seed is produced. Crimson clover has similar climatic requirements and is also widely grown in the South as a winter annual.

Tobacco.—Tobacco seed is usually planted in seedbeds that are protected by glass or cloth covers. Germination and growth are slow with mean temperatures of 50° to 60° and the optimum is about 75° to 80° whereas 95° or higher is very detrimental. In the northern states, the young plants are transplanted in late May or early June, and it is rare that they are damaged by late freezes. Delayed planting there involves the risk of fall freezes, and at the time of maturity, the crop is quite susceptible to damage. In the South, the crop is transplanted early because high soil temperatures and strong sunlight can permanently stunt or kill the plants.

A wet winter and spring may make seedbed preparation difficult and interfere with the process of soil sterilization. The amount of rain and the condition of the soil are quite important at the time of transplanting. Very dry weather entails the artificial watering of each plant as it is set. Excessive rain and humidity are conducive to damping-off and other diseases. Temperatures above 95° and bright sunshine may burn the leaves, especially during periods of drought.

The large leaf area makes for high transpiration and tobacco needs plenty of rain. During the 90 days of the normal growing season, it receives about 11 in. to 14 in. in the northern and central areas, and 15 in. to 16 in. in the extreme southeast. The large leaf area also makes the plant very sensitive to wind and hail storms.

The modification of microclimate is practiced during the curing time as well as during seedling. Humidity control is accomplished by different ventilation methods in the barn. The several types of tobacco have their own optimum weather condition. Shade grown tobacco, growing the crop under nets, in Connecticut and other areas, is an example of the modification of microclimate to produce a desired quality of tobacco, fine cigar wrappers.

Sugar Crops.—The two sugar crops, beets and cane are favored by quite different climatic optimums. The former is grown in the northern part of the humid area, and the latter in the semi-tropical areas of Louisiana and Florida.

Sugar beet seed will germinate at a temperature of only slightly above freezing, but to reduce rot, should not be planted in temperatures less than 50°, and will germinate and grow even better with a temperature near 60°. The seedlings are quite sensitive to cold and will be killed by temperatures in the high 20's, but after a week or so, they are able to withstand frost and freezing temperatures. During the summer, crop growth is efficient with a mean temperature of 70° or a little higher. The accumulation of sugar is retarded by temperatures above the mid 80's which, in part, accounts for its ill adaptation in the South. Adequate moisture is necessary in the summer. The seasonal rainfall for efficient production is about 10 in. to 15 in., and areas with less than this amount are normally irrigated. Cool fall temperatures in the north of the humid area promote increased sugar content.

Sugar cane is commercially planted in stalk strips 2 ft to 3 ft long. In Louisiana, it is normally planted in the fall, and only a few areas a little further north are planted in spring. The plant requires 8 to 24 months to reach maturity. Each crop is usually cut twice. Following 8 months of temperatures high enough to promote vegetative growth, a short cool period promotes sugar accumulation. During the winter, the stub from the first year's

growth, or the new stalk seedlings are covered with dirt as a protection from the cold. In spring, the dirt is removed leaving a narrow bed that warms up quickly to start spring growth. In addition to needing relatively high summer temperatures, as in opposition to sugar beets, the cane needs a bountiful supply of moisture, however, adequate drainage for excess rain is also essential.

To a degree, sugar production in the humid areas is favored by cool weather in the North for beets, and warm weather in the South for cane.

Vegetables.—Vegetables need a good deal of rain and are chiefly grown in areas of 30 in. to 40 in. of yearly rain or areas with irrigation. Of all the vegetables, only a few varieties of beans can be considered dry-weather plants. Low humidities with drying winds of summer damage the flowers of certain plants and retard the number of fruit that can be set.

Temperature has less influence on vegetable production than moisture, as nearly all sections have weather warm enough for all except a few tropical vegetables. The season of warm weather, of course, limits winter production to the extreme South. In the mid-south, some areas grow a double crop, one in spring and another in fall, avoiding the extremes of winter and summer.

In the South, the high summer temperatures, even when combined with adequate moisture limits vegetable production. Insects and diseases thrive in the warm moist summer weather. The vegetables develop rapidly and must be harvested at the proper moment to avoid over ripening. This ripening goes on even after the crop is harvested. In some plants, the high temperatures and consequent high rate of transpiration accelerate the loss of sugars and thus changes the flavor, even when there is no visible change. Lettuce is subject to leafburn with high temperatures, and other leafy vegetables, such as spinach and cabbage, lose their best flavor. Even some warm weather crops suffer from high temperatures. Tomatoes scald when exposed to the sun and even hardy beans may be damaged. For these reasons, most of the summer vegetables are grown under the cooler conditions of the North.

The potato is a cool weather crop and grows best in the northern part of the humid region, however, a good early variety crop is grown in the South. High temperatures injure the tuber. Freeze injury is most common in the South and affects the winter or early spring crop. In the North, the season is cut short at times by early freezes, however, if the freeze is not too severe, the harvest is aided because the plants drop their leaves. Potatoes that are frozen are seriously damaged. Even when stored at a temperature just above freezing, they are rendered unpalatable as the starch is converted to sugar. The soil moisture must give an even supply of water or the potato will be knobby and lowered in the market value. Potato late blight is a serious problem, because the weather that favors this disease, also generally favors potato growth. There are a number of forecast procedures to warn of disease development. All are dependent on optimum temperatures, 50° to 80°, and wet leaf surfaces. The Department of Agriculture in the northcentral states provides forecasts of this disease's development, utilizing field reports and long-term forecasts of the USWB (14).

Sweet potatoes will not thrive in cool weather. No other common crop in the United States will stand so much heat and very few require as much. Most of the commercial crop is grown south of the 75° average summer temperature line, except for the area of Maryland, Delaware, and New Jersey, and some smaller areas of Iowa through southern Indiana. The sweet potato is a source of starch, and for this use, the crop is limited to the South with a

July-August temperature above 80°. The western limit of culture is in central Texas or just beyond the humid area. The crop does best where annual rainfall is over 35 in. except for irrigated areas. Day-length does not affect root development, but the vegetative growth is favored by long summer days. Sweet potato roots are bedded in warm soil for 4 wk to 6 wk, and then the sprouts are pulled and planted after the mean temperature approaches 70°. Prolonged exposure of leaves or roots much below 50° will damage or destroy the crop. Only a very light frost will kill the foliage.

Fruits.—Tropical fruits, such as bananas, breadfruit, coconuts, Brazil nuts, coffee, and cocoa cannot withstand a freeze, and even periods in the low 40's hurt the crop. This limits commercial production to only the extreme southern part of the eastern humid region.

Sub-tropical fruits, such as citrus, olives, figs, and dates, will tolerate temperatures slightly below freezing, if in the correct stage of development. They need a little cooler weather than is found in the tropics for proper development.

Most citrus have a optimum temperature from the mid 70's to the low 90's. Growth practically stops below 55°F or above 100°F. Normal yearly precipitation requirements are estimated at about 35 in. Winds not only give some direct injury, but loss of fruit occurs due to excessive drying. Fairly high relative humidity seems to be associated with high quality fruit.

Date palms can endure lower temperatures than citrus and in a dormant state, are rarely injured by 20°F. Figs can stand 15°F in a dormant state. Moisture requirements of dates and figs are less than those of citrus, and wet weather is injurious by direct damage and by promoting insects and diseases.

Hardy fruits, such as apples, peaches, pears, cherries, plums, prunes, grapes, and apricots can stand temperatures considerably below freezing during the dormant stage. Deciduous fruit trees all require a certain amount of cold during the winter or the buds will not open in spring. Apples and most peaches need 600 to 900 hr of temperatures below 45°F. This limits their production along the Gulf coast.

During winter, root injury due to very cold weather can kill trees, but a cover crop protects that area. Fruit buds are sensitive to cold and are frequently killed by low winter temperatures that do not injure the rest of the tree. During the spring, a sharp freeze following a mild period can kill apple trees with readings of zero in the North and 15 in the South. Various fruits differ greatly in the amount of heat needed to expose the sensitive flower parts, and this determines the susceptibility to spring frosts. The apple requires the greatest amount of warm weather to bloom, and therefore is the least likely to be caught by spring freezes. The apricot requires the least heat and is the most likely to be injured.

All fruits in this group need ample water and 30 in. of yearly precipitation in the natural limit. The early ripening fruits, such as cherries and apricots, do not need quite as much water as the late maturing peaches, apples, and pears. Cherries thrive with an average summer temperature of about 65°F, apples 65° to 75°F, pears a little higher, and peaches in areas of above 75°F. Most fruits are susceptible to disease and many have the same optimum conditions, thus good fruit weather is usually good disease weather.

Grapes that grow in the humid area will endure temperatures that kill peach trees and they approach the hardiness of apples. All grapes are resistant to drought as compared with tree fruits. Many types of grapes are susceptible

to fungus diseases, however some varieties grown in the southeast have resistance. For quality, grapes need a good deal of sunshine. In some European areas, sunshine is increased by the use of reflectors.

Strawberries are grown in all parts of the humid region. In the North, they must be protected by mulching or some other process from the cold, and in the humid East, varieties that are resistant to fungus diseases must be used. Most strawberry varieties are short-day plants. In the North, all fruit buds are formed in the fall; in the South, fruit buds form in the fall and also in the spring.

Pecans need a 200-day frost-free season and a long hot growing season to mature the nut. A shorter period of cold weather is sufficient to break dormancy in pecans than most deciduous fruits. About 40 in. to 50 in. of well distributed rain or irrigation is normal for a mature orchard.

Walnuts are quite susceptible to fungus diseases in very humid regions. Very high summer temperatures are detrimental to walnuts, and in winter, cold requirements to break dormancy are high in many varieties. Growth starts early in spring and late frosts are a serious hazard. The black, or American walnut is a native of the United States and grows well in all but the extreme north and south areas of the humid region.

SUMMARY

Climatic influence on crop production goes far beyond the obvious limiting effect of drought or flood and searing heat or freezing cold. Each crop has its own optimum value of the weather variables: precipitation, temperature, sunlight and day-length, humidity, and evaporation. Also, the various farm practices necessary to raise a crop efficiently are greatly influenced by these weather variables. In addition, the weather variables themselves have great variation over the humid area. To evaluate an agricultural procedure, the variation of weather, the crop-weather relationship, and the crop practice-weather relationship must all be considered.

Specific considerations for the engineer engaged in designing procedures for increasing farm efficiency in humid areas include the following (1). The indications are strong that supplemental irrigation during certain critical periods of the crop cycle will increase most crop yields, even in humid regions (2). Only a small part of the heat received from the sun is actually put to efficient use, and this large potential power supply might be utilized by modified farm practices (3). The large moisture supply makes the control of insects, diseases, and weeds, and the techniques of tillage and fertilization of particular importance in humid areas (4). The modification of certain phases of the microclimate, temperature, sunlight, and evaporation, has demonstrated spectacular increases in crop efficiency in small areas and awaits the development of procedures for the spread of these modifications over large areas.

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DISCUSSION

ANNUAL DROUGHTS[a]

Closure by M. C. Boyer

M. C. BOYER,[1] F. ASCE.—The author appreciates very much the data which Messrs. Minshall and Woolhiser have presented in their discussion of his paper. They show in striking fashion the effects on crop yields of precipitation distribution during the critical months of July and August, as contrasted with that during the growing period April to September.

The extremely spotty nature of summertime precipitation introduces a factor of great complexity into any attempt to correlate crop yield with rainfall. If it could be possible to have each farmer observe and record precipitation data, which might be correlated with his crop yield, the resultant intensive covering of a state, such as Iowa, would yield data of great value in a study of the effects of precipitation on crop yield.

[a] September, 1959, by M. C. Boyer.
[1] Hydraulic Engr., Indiana Flood Control and Water Resources Commission.

LEGAL ASPECTS OF GROUND WATER UTILIZATION[a]

Closure by Robert O. Thomas

ROBERT O. THOMAS,[1] F. ASCE.—The discussion of the basic paper has served to illustrate and emphasize the multi-faceted nature of the problems encountered in the development and utilization of ground water. Although the discussions were few in number, each of the discussers has been prominently identified with ground water development in the course of his career and their remarks carry the weight of authoritative experience. It is unfortunate that no discussion was received from a member of the legal profession, although many copies of the paper were circulated to that end.

Mr. Kazmann raises the question of the right to dispose of unwanted or undesired water. While there has not been, so far as the writer is aware, any legislation providing for the acquisition of the right to the "beneficial waste" of water, the fact of such waste has been recognized in legislation directed toward other purposes. Typical instances where this has occurred are laws relating to the construction and operation of flood control facilities; the recognized right to protect oneself against the elements; laws providing for the drainage and reclamation of swamp and overflow lands; and water pollution control legislation.

The latter recognizes, by implication, that liquid waste, such as the frequency acid mine drainage and the brines produced in oil development do, in fact, exist. Pollution control legislation provides the means of regulating such discharges to alleviate damage to otherwise usable receiving waters. It appears to the writer that the required wastage of certain portions of our water supplies has heretofore been principally provided for under governmental police and welfare powers and functions and by civil actions for damage, when such result has been associated with the means of disposal. It may be, however, that the increasing complexity of our civilization may eventually require specific legislation relating to what is termed, by Mr. Kazmann, "beneficial waste."

Mr. Hotes very properly points out that ground water problems are not the exclusive province of the engineer. The writer has recognized this fact repeatedly[2] and can only plead that this paper was limited to a single aspect of a wide-ranging subject. The writer agrees that much of the apparent legal confusion with regard to ground water is traceable to the disparity of opinion generally presented for the consideration of the court. This could, of course, be minimized if the oft-repeated suggestion that factual physical and technical testimony should be presented by qualified scientists and engineers appointed

a December, 1959, by Robert O. Thomas.

1 Superv. Hydr. Engr., State Dept. of Water Resources, Sacramento, Calif.

2 Discussion by Robert O. Thomas, of "Ground Water Problems in New York and New England," Proceedings, ASCE, Vol. 85, No. HY 11, November, 1959.

directly by the court, with fees assessed equally to each of the litigants, is followed in practise.

Mr. Hotes has quite properly raised the question of the priority of industrial use of water. During the distant, and recent, past, when our theories of water rights were in the process of formulation and codification, the principal municipal use of water was for domestic purposes. Most of the industrial use which occurred prior to the period of the Civil War consisted of using water supplies for the purpose of producing power, such as in the operation of water wheels. With the growth of mass industry, the transfer of food product processing from the home to the factory, and the advent of new chemical products and processes, the present-day use of water by industry is frequently a major portion of the municipal requirement. With ever-increasing development of our water resources, the question of priority of water use between the industry which gives employment and the farm which produces food will, in many cases, become of prime importance.

The writer is appreciative of Mr. Baumann's contribution, particularly with regard to the proper assessment of credit for the origination and support of water replenishment district legislation in California. The original paper, of course, was general and impersonal in nature, and Mr. Baumann's review constitutes a valuable addition to the history of water legislation in this country.

WORLD PRACTICES IN WATER MEASUREMENT AT TURNOUTS[a]

Discussion by Lee Chow

LEE CHOW,[17] F. ASCE.—The author is to be complimented for this fairly complete review of the turnout structures for control and measurement of water. It is interesting to note the various types of turnout structures in use around the world. Although the author did not try to evaluate them, the discussions and future studies might bring out further information so that an evaluation could be made later on.

The turnout designs shown in Figs. 1, 2, 5, 6, and 12 are ingeneous. One drawback is there is no provision to shut off the flow when so required. Therefore, a simple perfection seems possible if gates are incorporated in these structures. The use of all the divisors shown in Figs. 7, 8, and 9 has, presumably, taken into account of the relative conveyance losses in the laterals due to their different lengths and the different soils they go through. That is, the discharges in the laterals are not strictly in proportion to the respective commanded areas.

The turnout structures, as the author mentioned, involve control and measurement of flows. In order to achieve this, either a combined structure or two separate structures are necessary. For the irrigation works in Taiwan, both types are in use. The combined types are the constant head orifices and the movable weirs. The separate types consist of a gate and some measuring device, either a standard weir, contracted or suppressed, or a Partial flume of free flow or submerged flow. All gates can be locked at any gate opening with a combination lock incorporated in the gate hoist. All these gates require some manipulation for the desired amount of flow. Once the operators are trained, they do not have any difficulty. Some experiences may be useful for the designers. Weirs and control gates have to be far enough apart to be free of turbulence of flow which makes reading difficult and inaccurate, but not unnecessarily far apart to cause inconvenience of operation. The air vents required for the suppressed weirs should be large enough to supply sufficient air under the nappe of the falling water. In some canal, sediment may get behind the weir and affect the accuracy of measurement. In case of Partial flumes, proper selection of color and material for the staff in the stilling wells in necessary for easy reading.

In north Afghanistan, steel, iron and skill labor are often unavailable. In order to achieve some control and measurement of water, a wooden slide turnout shown in Fig. 25 was devised by the writer. This device consists of mainly a fixed weir for flow measurement and a wooden sliding gate, attached to the weir, for water control. It requires mostly local material with very small amount of steel. Some inaccuracy of measurement is to be expected

[a] June, 1960, by Charles W. Thomas.

[17] Irrigation Engr., Food and Agriculture Organization of the United Nations, United Nations Technical Assistance Mission, Kabul, Afghanistan.

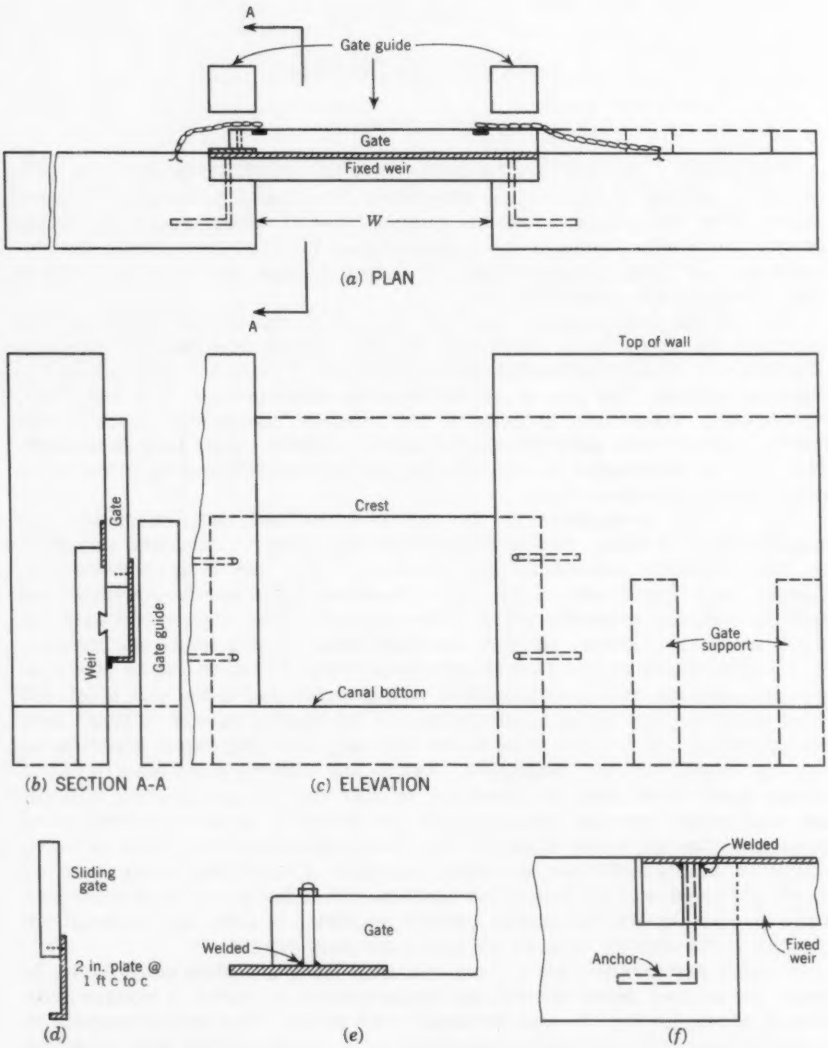

FIG. 25.—WOODEN SLIDE TURNOUT

due to imperfect conformity with the weir standards. The slide gate will be easy to operate because it does not have much pressure due to its small height, yet it will not float since there are catches at its bottom. The gate can be locked at any opening using chains and locks. By varying the widths of the weirs, it can easily be used for discharges up to about 20 cfs. In places where water control is important and urgent but only simple devices can be used, this sliding turnout may be useful. In such places, any design involving skillful workmanship and imported materials will be difficult for the water users to adapt.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 2270 is identified as 2270(ST9) which indicates that the paper is contained in the ninth issue of the Journal of the Structural Division during 1959.

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DECEMBER: 2271(HY12)[c], 2272(CP2), 2273(HW4), 2274(HW4), 2275(HW4), 2276(HW4), 2277(HW4), 2278(HW4), 2279(HW4), 2280(HW4), 2281(IR4), 2282(IR4), 2283(IR4), 2284(IR4), 2285(PO6), 2286(PO6), 2287(PO6), 2288(PO6), 2289(PO6), 2290(PO6), 2291(PO6), 2292(SM6), 2293(SM6), 2294(SM6), 2295(SM6), 2296(SM6), 2297(WW4), 2298(WW4), 2299(WW4), 2300(WW4), 2301(WW4), 2302(WW4), 2303(WW4), 2304(HW4), 2305(ST10), 2306(CP2), 2307(CP2), 2308(ST10), 2309(CP2), 2310(HY12), 2311(HY12), 2312(PO6), 2313(PO6), 2314(ST10), 2315(HY12), 2316(HY12), 2317(HY12), 2318(WW4), 2319(SM6), 2320(SM6), 2321(ST10), 2322(ST10), 2323(HW4)[c]. 2324(CP2)[c], 2325(SM6)[c], 2326(WW4)[c], 2327(IR4)[c], 2328(PO6)[c], 2329(ST10)[c], 2330(CP2).

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JANUARY: 2331(EM1), 2332(EM1), 2333(EM1), 2334(EM1), 2335(HY1), 2336(HY1), 2337(EM1), 2338(EM1), 2339(HY1), 2340(HY1), 2341(SA1), 2342(EM1), 2343(SA1), 2344(ST1), 2345(ST1), 2346(ST1), 2347(ST1), 2348(EM1)[c], 2349(HY1)[c], 2350(ST1), 2351(ST1), 2352(SA1)[c], 2353(ST1)[c], 2354(ST1).

FEBRUARY: 2355(CO1), 2356(CO1), 2357(CO1), 2358(CO1), 2359(CO1), 2360(CO1), 2361(PO1), 2362(HY2), 2363(ST2), 2364(HY2), 2365(SU1), 2366(HY2), 2367(SU1), 2368(SM1), 2369(HY2), 2370(SU1), 2371(HY2), 2372(PO1), 2373(SM1), 2374(HY2), 2375(PO1), 2376(HY2), 2377(CO1)[c], 2378(SU1), 2379(SU1), 2380(SU1), 2381(HY2)[c], 2382(ST2), 2383(SU1), 2384(ST2), 2385(SU1)[c], 2386(SU1), 2387(SU1), 2388(SU1), 2389(SM1), 2390(ST2)[c], 2391(SM1)[c], 2392(PO1)[c].

MARCH: 2393(IR1), 2394(IR1), 2395(IR1), 2396(IR1), 2397(IR1), 2398(IR1), 2399(IR1), 2400(IR1), 2401(IR1), 2402(IR1), 2403(IR1), 2404(IR1), 2405(IR1), 2406(IR1), 2407(SA2), 2408(SA2), 2409(HY3), 2410(ST3), 2411(SA2), 2412(HW1), 2413(WW1), 2414(WW1), 2415(HY3), 2416(HW1), 2417(HW3), 2418(HW1)[c], 2419(WW1)[c], 2420(WW1), 2421(WW1), 2422(WW1), 2423(WW1), 2424(SA2), 2425(SA2)[c], 2426(HY3)[c], 2427(ST3)[c].

APRIL: 2428(ST4), 2429(HY4), 2430(PO2), 2431(SM2), 2432(PO2), 2433(ST4), 2434(EM2), 2435(PO2), 2436(ST4), 2437(ST4), 2438(HY4), 2439(EM2), 2440(EM2), 2441(ST4), 2442(SM2), 2443(HY4), 2444(ST4), 2445(EM2), 2446(ST4), 2447(EM2), 2448(SM2), 2449(HY4), 2450(ST4), 2451(HY4), 2452(HY4), 2453(EM2), 2454(EM2), 2455(EM2)[c]. 2456(HY4)[c]. 2457(PO2)[c], 2458(ST4)[c]. 2459(SM2)[c].

MAY: 2460(AT1), 2461(ST5), 2462(AT1), 2463(AT1), 2464(CP1), 2465(CP1), 2466(AT1), 2467(AT1), 2468(SA3), 2469(HY5), 2470(ST5), 2471(SA3), 2472(SA3), 2473(ST5), 2474(SA3), 2475(ST5), 2476(SA3), 2477(ST5), 2478(HY5), 2479(SA3), 2480(ST5), 2481(SA3), 2482(CO2), 2483(CO2), 2484(HY5), 2485(HY5), 2486(AT1)[c], 2487(CP1)[c], 2488(CO2)[c], 2489(HY5)[c], 2490(SA3)[c], 2491(ST5)[c], 2492(CP1), 2493(CO2).

JUNE: 2494(IR2), 2495(IR2), 2496(ST6), 2497(EM3), 2498(EM3), 2499(EM3), 2500(EM3), 2501(SM3), 2502(EM3), 2503(PO3), 2504(WW2), 2505(EM3), 2506(HY6), 2507(WW2), 2508(PO3), 2509(ST6), 2510(EM3), 2511(EM3), 2512(ST6), 2513(HW2), 2514(HY6), 2515(PO3), 2516(EM3), 2517(WW2), 2518(WW2), 2519(EM3), 2520(PO3), 2521(HY6), 2522(SM3), 2523(ST6), 2524(HY6), 2525(HY6), 2526(HY6), 2527(IR2), 2528(ST6), 2529(HW2), 2530(IR2), 2531(HY6), 2532(EM3)[c], 2533(HW2)[c], 2534(WW2), 2535(HY6)[c], 2536(IR2)[c], 2537(PO3)[c], 2538(SM3)[c], 2539(ST6)[c], 2540(WW2)[c].

JULY: 2541(ST7), 2542(ST7), 2543(SA4), 2544(ST7), 2545(ST7), 2546(HY7), 2547(ST7), 2548(SU2), 2549(SA4), 2550(SU2), 2551(HY7), 2552(ST7), 2553(SU2), 2554(SA4), 2555(ST7), 2556(SA4), 2557(SA4), 2558(SA4), 2559(ST7), 2560(SU2)[c], 2561(SA4)[c], 2562(HY7)[c], 2563(ST7)[c].

AUGUST: 2564(SM4), 2565(EM4), 2566(ST8), 2567(EM4), 2568(PO4), 2569(PO4), 2570(HY8), 2571(EM4), 2572(EM4), 2573(EM4), 2574(SM4), 2575(EM4), 2576(EM4), 2577(HY8), 2578(EM4), 2579(PO4), 2580(EM4), 2581(ST8), 2582(ST8), 2583(EM4)[c], 2584(PO4)[c], 2585(ST8)[c], 2586(SM4)[c], 2587(HY8)[c].

SEPTEMBER: 2588(IR3), 2589(IR3), 2590(WW3), 2591(IR3), 2592(HW3), 2593(IR3), 2594(IR3), 2595(IR3), 2596(HW3), 2597(WW3), 2598(IR3), 2599(WW3), 2600(WW3), 2601(WW3), 2602(WW3), 2603(WW3), 2604(HW3), 2605(SA5), 2606(WW3), 2607(SA5), 2608(ST9), 2609(SA5)[c], 2610(IR3), 2611(WW3)[c], 2612(ST9)[c], 2613(IR3)[c], 2614(HW3)[c].

OCTOBER: 2615(EM5), 2616(EM5), 2617(ST10), 2618(SM5), 2619(EM5), 2620(EM5), 2621(ST10), 2622(EM5), 2623(SM5), 2624(EM5), 2625(SM5), 2626(SM5), 2627(EM5), 2628(EM5), 2629(ST10), 2630(ST10), 2631(PO5)[c], 2632(EM5)[c], 2633(ST10), 2634(ST10), 2635(ST10)[c], 2636(SM5)[c].

NOVEMBER: 2637(ST11), 2638(ST11), 2639(CO3), 2640(ST11), 2641(SA6), 2642(WW4), 2643(ST11), 2644(HY9), 2645(ST11), 2646(HY9), 2647(WW4), 2648(WW4), 2649(WW4), 2650(ST11), 2651(CO3), 2652(HY9), 2653(HY9), 2654(ST11), 2655(HY9), 2656(HY9), 2657(SA6), 2658(WW4), 2659(WW4)[c], 2660(SA6), 2661(CO3), 2662(CO3), 2663(SA6), 2664(CO3)[c], 2665(HY9)[c], 2666(SA6)[c], 2667(ST11)[c].

DECEMBER: 2668(ST12), 2669(IR4), 2670(SM6), 2671(IR4), 2672(IR4), 2673(IR4), 2674(ST12), 2675(EM6), 2676(IR4), 2677(HW4), 2678(ST12), 2679(EM6), 2680(ST12), 2681(SM6), 2682(IR4), 2683(SM6), 2684(SM6), 2685(IR4), 2686(EM6), 2687(EM6), 2688(EM6), 2689(EM6), 2690(EM6), 2691(EM6)[c], 2692(ST12), 2693(ST12), 2694(HW4)[c], 2695(IR4)[c], 2696(SM6)[c], 2697(ST12)[c].

c. Discussion of several papers, grouped by divisions.

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PART 2

DECEMBER 1960 — 43
VOLUME 86

NO. IR4
PART 2

Your attention is invited

NEWS
OF THE
IRRIGATION
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AMERICAN SOCIETY OF CIVIL ENGINEERS
FOUNDED 1852

JOURNAL OF THE IRRIGATION AND DRAINAGE DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

NEWS

December, 1960

PURPOSE OF THE IRRIGATION AND DRAINAGE DIVISION

"To promote advancement in thought and practice in the field, to clarify fundamental principles, to disseminate knowledge of current practice and the results obtained therefrom, and to bring about closer acquaintance of those engaged in irrigation and drainage engineering. The field of work of the Irrigation and Drainage Division includes all engineering concerned with the application of water to land or the removal of water therefrom and all of the technical, economic, and social aspects of the association of engineering with these problems. In brief, it covers all phases of irrigation, drainage, and reclamation of lands."

* * * * *

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Note.—No. 1960-43 is Part 2 of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 4, December, 1960.

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902 East "G" Street, McCook, Nebraska

* * * * *

The Society year runs from October 1 to September 30 and thus we are now entering another year of division activity. The following is a revised list of members of the Committees of the Irrigation and Drainage Division:

Committee on Publications - - Dean F. Peterson, Jr., Chairman; Charles L. Barker; Harry F. Blaney, Sr.; Calvin C. Warnick; Eldred R. Harrington; and Daryl B. Simons.

Committee on Cooperation with Local Sections - - S. Mark Davison, Chairman; Rowland W. Fife; G. Marvin Litz; and Arthur D. Soderberg

Committee on Session Programs - - Herbert E. Prater, Chairman; Paul H. Berg, Vice-Chairman; and Henry S. Raymond

Committee on Consolidation and Progressive Betterment of Old Irrigation Systems - - A. Alvin Bishop, Chairman; George D. Clyde; John E. Hayes; Dean F. Peterson, Jr.; and Luther M. Winsor

Committee on Drainage of Irrigated Lands - - Edwin W. Elliott, Chairman; C.R. Maierhofer; William W. Donnan; Orson W. Israelsen; Harry Rubey; and Lyman O. Willardson

Committee on Ground Water - - H. O. Banks, Chairman; Harris R. McDonald; Cleve H. Milligan; Harold C. Schwalen; and Robert O. Thomas

Committee on Irrigation and Drainage Practices in Humid Areas - - Marion C. Boyer, Chairman; Paul H. Berg; Leo F. Reynolds; Harold A. Scott; and Elmer W. Gain

Task Committee on Water Rights Laws in States in Humid Areas - - James I. Seay, Jr., Chairman; John J. Ledbetter; George G. Shanklin; Robert L. Smith; and Donald P. Schiesswohl

Committee on Research - - Gerald B. Keesee, Chairman; Maurice L. Albertson; Robert L. Hardman; Deil G. Shockley; and C. Walter Thomas

Committee on Water Conservation - - Harry F. Blaney, Sr., Chairman; Arthur E. Bruington; Lloyd E. Myers, Jr.; P. H. McGaughy; and Leonard Schiff

Task Group on Methods of Conserving Water - - Arthur E. Bruington, Chairman; William T. Balch; Donald H. McKillop; and Gerald E. Carlat

Task Group on Consumptive Use of Water - - Harry F. Blaney, Sr., Chairman; Wayne D. Criddle; Clyde E. Houston; G. Marvin Litz; and Arnold I. Johnson

Task Group on Re-Use of Drainage Water - - Lloyd E. Myers, Jr., Chairman; Lyman S. Willardson; Keith E. Anderson; August R. Robinson; and F. Marion Warnick

Task Group on Water Management - - Leonard Schiff, Chairman; Charles W. Thomas; Robert Edmonston; C. Warren Hink; and Myles R. Howlett

Task Group on Water Quality - - P. H. McGauhey, Chairman; Albert F. Bush; William W. Aultman; David B. Willets; and Martin R. Huberty

* * * * *

CALENDAR OF EVENTS

April 10-14, 1961. National Convention, ASCE, Phoenix, Arizona. Hotel Westward Ho. The Irrigation and Drainage Division plans to sponsor five half-day sessions as part of a week-long coordinated program devoted to water resources. This will constitute the Irrigation and Drainage Division technical conference for 1961.

June 26-July 2, 1961. 7th Congress, International Committee on Large Dams, Rome, Italy.

October 16-20, 1961. National Convention, ASCE, New York. Hotel Statler. No Irrigation and Drainage Division Sessions.

February 1962. National Convention, ASCE, Houston, Texas

May 1962. National Convention, ASCE, Omaha, Nebraska

October 15-19, 1962. National Convention, ASCE, Detroit, Michigan.

March 1963. National Convention, ASCE, Atlanta, Georgia.

October 1963. National Convention, ASCE, San Francisco, California.

The Irrigation and Drainage Division plans to sponsor four half-day sessions at the Houston, Omaha, Detroit, and Atlanta conventions and six sessions at the San Francisco convention. A number of general topics and specific papers already have been proposed for some of these meetings; any further suggestions should be sent to Herbert Prater or Paul Berg, Chairman and Vice-Chairman, respectively, of the Committee on Session Programs.

* * * * *

ANNUAL REPORT OF COMMITTEES

The annual report of the Committees of the Irrigation and Drainage Division for the past fiscal year has been published. It outlines the programs carried on by each of the Committees together with their accomplishments and presents a record of which all Division members should be proud.

One of the major efforts of the Division has been in the field of coordinating our water resources program with those of the other Divisions. A continuation and extension of this cooperative work with other Divisions working with water resources should be of benefit to all.

The following is a summarization of the accomplishments of each Committee and Task Group for the past year:

The Committee on Publications received 39 papers, reviewed 37 papers, recommended 35 papers, and published 31 papers in four issues of the Journal. The March 1960 issue of the Journal contained 14 papers dealing with the subject of Weather Modification. There were 32 separate discussions of Journal papers published during the year.

The Committee on Cooperation with Local Sections held one meeting in Reno, Nevada on June 22, 1960. Every Local Section of ASCE has been contacted and an Irrigation and Drainage Division representative has been designated. This roster is being kept current and up-to-date. The committee is now in the process of gathering information and data about each technical committee of the Division for distribution to the Local sections. The committee is also writing to each Local Section representative to urge the scheduling of one meeting a year on the general subject or theme of Water Resources.

The Committee on Session Programs is now geared to planning technical sessions one year in advance and is going to attempt to reach its goal of planning two years in advance. To this end they have tentatively scheduled the following future session programs:

April	1961	Phoenix	11 papers in the Symposium on Water Resources
Feb.	1962	Houston	4 half-day sessions
May	1962	Omaha	4 half-day sessions
Oct.	1962	Detroit	4 half-day sessions
March	1963	Atlanta	4 half-day sessions
Oct.	1963	San Francisco	6 half-day sessions

The Committee on Consolidation and Betterment of Old Irrigation Systems held no formal meetings, but continued to carry on its work by correspondence.

The Committee on Drainage of Irrigated Lands has been revamped and several new members have been appointed. While no meetings were held during the year, the Committee's work was carried on by correspondence. A number of papers were sponsored by this committee during the past year, as follows:

"Drainage in the Coachella Valley of California," by Lowell Weeks
"Irrigation and Drainage in West Pakistan," by R. J. Tipton
"Irrigation and Drainage in Australia," by Martin R. Huberty
"Drainage and Water Management in Wester Europe," by W. W. Donnan
"Irrigation and Drainage Projects in Uruguay," by J. E. Christiansen
"Well Point Device for Measuring Hydraulic Conductivity," by W. W. Donnan

The Committee on Ground Water: Control Group has had a very active year. Working by correspondence, all the chapters of its proposed "Manual of Ground Water Basin Management" were revised, reviewed, edited, and produced in mimeographed form. This manual was presented to the Executive Committee for review in May, 1960. The manual was reviewed and approved for publication by the Society's Committee on Publications as a Manual of Engineering Practice of the Society. The manuscript is now in the hands of Manager of Technical Publications, ASCE. An order coupon for the Manual will appear in CIVIL ENGINEERING in early 1961 and in the next issue of this Newsletter.

The Ground Water Committee met in Sacramento, California on July 23, 1960 for the purpose of consideration of future work. It was decided that the general objective should be to continue the study of hydrologic, hydraulic, economic, legal, administrative, political, operational, and financial problems of ground water management. Specific activities included under this general objective would be to stimulate studies concerning methods of, and actual results from, ground water management as practiced in various parts of the country, and the presentation of the papers thereon.

Ground Water management was defined as: Any organized effort to achieve better and more efficient long-range utilization of ground water resources, including ground water storage capacity, through one or more of the following means: administrative control, conservation, artificial recharge, quality protection and planned withdrawal of ground water from subsurface storage.

Several papers were suggested for consideration at the Houston Convention in 1962, as follows:

"Ground Water Basin Management in Ventura County"
"Status of Ground Water Replenishment in Los Angeles County"
"Ground Water Basins in the Seventeen Western States"
"An Inventory of Agencies Engaged in Ground Water Basin Management"

The Committee on Irrigation and Drainage Practices in Humid Areas has been working on the preparation of material for a manual, handbook, or source book on irrigation and drainage practices. An outline, entitled "Irrigation," was submitted to the Executive Committee and approved. This outline is to be used as a guide in compiling chapters on Irrigation practices. The committee held one meeting on March 7 at New Orleans, Louisiana. At that time several chapters of the handbook were reviewed. During the year this committee sponsored a number of papers at technical sessions as follows:

"Irrigation and Watershed Development Program," by Elmer Gain
"Removal of Storm Water from Irrigated Lands," by Leo Reynolds
"Methods of Applying Irrigation Water," by Paul Berg
"Characteristics of Humid Areas," by Cliff Boyer
"Effects of Humid Area Irriation on Crop Production," by Harold Scott

The Task Committee on Water Rights Laws in States in Humid Areas met in Memphis, Tennessee on November 6-7, 1959 to study various facets of a model law of and for water rights in humid areas. As a result of this meeting it was agreed that a paper be written and presented in New Orleans, Louisiana at the spring convention, ASCE, on this subject. This paper, entitled "Guides to Water Rights Laws" by Erby Seay, was presented.

The Committee on Research is one of the most active research committees of any of the ASCE Divisions. Several of the members participated in the second Research Conference ASCE held in Evanston, Illinois in September, 1959. One paper was presented "Private Foundations as Sources of Funding for Research in Civil Engineering," by Maurice Albertson. The Committee met in Santa Fe, New Mexico on January 8, 1960. The purpose of this meeting was to select the two highest priority projects needing research. These were as follows: (1) Methods of reducing reservoir evaporation; (2) Development of low-cost hydraulic structures for conveyance of water.

The Committee also sponsored a paper for the New Orleans Convention, entitled "Research Needs for Ground Water Recharge," by Sol Resnick.

The Committee on Water Conservation held one meeting on November 3, 1959 in Los Angeles, California. This Committee is composed of the five chairmen of five task groups and their main function is to coordinate the work on water conservation. The Committee, through its task groups, has sponsored three half-day sessions at the Reno Convention in June 1960 and has suggested eight papers for the forthcoming Phoenix Convention.

The Task Group on Consumptive Use of Water for Irrigated Crops and Native Vegetation is preparing several papers for eventual publication in the Journal on "Consumptive Use Around the World." During 1959 Chairman Blaney visited irrigated areas in Greece, Turkey, Israel, West Pakistan, India, Thailand, Hong Kong, Japan, and Hawaii. A list of publications is being

compiled on irrigation and consumptive use in foreign countries. A roster of engineers working in foreign countries who might be able to assist in this compilation is being prepared.

The following titles of papers for Division technical sessions at the Phoenix 1961 convention were proposed:

"Salvage of Water on the Gila River, Arizona"
"Sedimentation, Colorado River Below Hoover Dam"
"Sedimentation Problem Below Yuma, Arizona"
"Construction of the San Juan Dam to Increase Water Supply for Irrigation"
"The Seven Rivers Dam of the Pecos River Plan, New Mexico"
"Safe Yield from Upper Watersheds to Ground Water Basins in Arid Areas"
"Plastic-lined Lysimeters for Measuring Consumptive Use by Native Vegetation"
"Water Salvage in the Middle Rio Grande Valley, New Mexico"

The task group held a meeting in Reno, Nevada in June, 1960. At this meeting a review was made of a bibliography of 500 items on consumptive use, by Arnold Johnson. Also, it was agreed that several subjects for future study would be: (1) Evaporation suppression from soil surfaces; (2) Determination of effective rainfall; (3) Short term peak consumptive use values, and (4) Water losses by phreatophites.

Some of the papers prepared or published by the group during the past year are as follows:

"Monthly Consumptive Use Requirements by Irrigated Crops," by Harry F. Blaney, Journal of Division of Irrigation and Drainage
"Monthly Consumptive Use by Irrigated Crops in Western States," by Harry F. Blaney, Howard R. Haise, and Marvin E. Jensen (mimeographed paper, provisional)
"Determining Irrigation Requirements from Consumptive Use Water Rates," by Harry F. Blaney, Brussels Fifth International Congress, Belgium
"Irrigation Research and Water Utilization in Israel," by Harry F. Blaney (mimeographed)
"Consumptive Use of Ground Water by Phreatophytes and Hydrophytes," by Harry F. Blaney (mimeographed, provisional)
"Water Supplies and Their Uses in Iron, Washington, and Krane Counites of Utah," by Wayne D. Criddle
"Consumptive Use Studies in Souther Utah," by Wayne D. Criddle (preliminary draft)
"Drainage," by Clyde E. Houston (a short course, University of California)
"Area-Wide Drainage," by Clyde E. Houston and J. L. Meyer, Californa Agriculture, University of California
"Measuring Water for Irrigation," by Clyde E. Houston and V. H. Scott, University of California
"References on Evaporation and Transpiration," by T. W. Robinson and Arnold I. Johnson, prepared for publication in the Division Journal

The Task Group on Methods of Conserving Water has held one meeting in which general discussions were held concerning the scope of the group's purpose and on definitions of terms. Discussions led to better understanding of the interests and qualifications of the Committee members. It is planned to outline study areas and make assignments to the several Committee members.

The group proposed papers for sessions at the Reno and Phoenix Conventions as follows:

"Water Spreading Practices in Los Angeles County"
"Separan and Its Use in Water Spreading"
"A Collapsible Rubber Dam for Use in Diversion of Water"
"Water Spreading Practices in California"
"Water Reclamation in California"
"Typical Water Spreading Structures"
"Effect of Colorado River Water on Natural Ground Water Quality"

The Task Group on Water Reclamation for Irrigation has carried on its program to data via correspondence. The following program has been proposed: Conduct a survey of potential sources of industrial, municipal and agricultural waste waters, review the data obtained and prepare a report outlining the potential importance of available information for selected sub-areas or sites which are representative of larger areas where irrigation is or may be practiced on a significant scale. Data collected will include quantities of water available, water quality, probable cost of any necessary decontamination, location of sources in relation to agricultural lands, reliability of sources and other pertinent data as available. On the basis of the above survey, the following activities are anticipated: (1) Selection of the most important sources of waste waters suitable for reclamation and develop for each source type a summary report on reclamation methods and costs; (2) Development of information on the design of project and farmstead irrigation systems for re-use of irrigation waste water; and (3) Promotion of the development and distribution of information on water reclamation through presentation and publication of papers and articles.

The Task Group on Water Quality sponsored papers on a special Division program for the ASCE Convention at Reno in June 1960 concerned with the upgrading of the quality of saline waters for use in irrigation. A matter of particular concern for the future is that of water quality in semi-arid country. It is proposed that a closer look be given to the quality of water which is being used in arid countries in comparison with that of agricultural drainage waters which in the United States are considered to be unsuitable for re-use. From such a study a re-evaluation of water quality standards for irrigation may be made.

Pursuant to the second major purpose of the task group, members expect to submit or to ferret out papers on various projects of interest to the Division's Journal. Through personal contact and appeals at technical meetings the group will seek to encourage both the presentation of original papers and discussions of papers published by others in the Journal. One paper published in the Journal has excited some interesting discussion.

The Task Group on Water Management has held three meetings in Los Angeles at little or no cost to the society. These meetings were held in January, April, and June of 1960. The group is completing a questionnaire on "Watershed Management Studies in the United States" which will be sent soon to agencies concerned with research and investigations in various phases of water management. The questionnaire asks for brief statements on the physical setup, overall purpose of work and specific objectives, results (significant statements on continuing projects and on completed projects or abstracts on the latter), publications and reports. It is intended to compile these into a report for contributing agencies and other interested people.

At the April meeting outlines prepared on various phases of watershed management by members of the task group were read and discussed. Further work is required on these outlines, which cover the following phases: Watershed land management - snow, erosion, fire and control, and cover effect and manipulation; agricultural - water movements, water application, drainage, recharge, soil-water relationships; commercial and residential developments; and legislation administered by agencies which are sources of assistance to groups interested in the solution of local problems in the fields of flood control, water conservation, drainage, watershed protection, wild life enhancement, navigation, power development, pollution abatement and salinity control. It appeared that material covered by the outlines would permit short and long term contributions to interested parties. It was agreed that contributions that could be made in a relatively short period of time would be reported as soon as finished and not held up until all phases were completed.

It became apparent during the discussion that answers to the questionnaire would be helpful to the development of portions of the material contained in the outlines. It also became apparent that the letter transmitting the questionnaire would have to establish the scope of the information required. Considerable time was devoted to considering the major phases of water management to be tackled by the task group. It was agreed tentatively, pending additional future consideration, to limit at least for the time being the work of the task group to activities of man which influence soil-water relationships. For example, the task group is not concerned with the design of a structure (hydraulics) but in its influence on hydrology; it is not concerned with the effect of structures on the stability of banks, but on their effect on water levels; not too concerned with fertilizer-plant relationships, but with the effect of the plants on evapotranspiration.

This task group has sponsored four papers which have been presented during 1959 and 1960.

The Water Resources Coordinating Committee has one representative of the Irrigation and Drainage Division. The coordination of the work of all five Water Divisions is vital to the promotion of more emphasis on water resources by the society. This Committee has held two meetings during the fiscal year and has written a report of its findings and proposals. It has been instrumental in promoting a conference-type program coordinating the technical sessions of the five sessions for the Phoenix convention. It has promoted through cooperative effort with each Division Executive Committee the development of an estimated 50 percent increase in activity of these divisions in the water resource field.

The Executive Committee of the Irrigation and Drainage Division has recommended of the WRCC for an indefinite future period of time to further stimulate activity in the water resource field. The Water Resources Coordinating Committee is now being reorganized. Its newly proposed purpose has been outlined as follows:

To coordinate and supervise the new organization and activities which are expected to result from the very significant study made by the Horner Committee on Water Resources; to continuously review the progress being made by the five divisions to meet the Society's water resources objectives and recommend any needed revisions in organization required; to coordinate Division activity in programing and presentation of technical information on water resources at conventions and conferences; to coordinate Division endeavors to

avoid conflicts, and to develop committee structure in new areas of technical interest in the field of water supply and conservation.

* * * * *

GROUND WATER BASIN MANAGEMENT MANUAL SOON TO BE AVAILABLE

As previously mentioned under the accomplishments of the Committee on Ground Water, their new manual on "Ground Water Basin Management" should be available to the profession in early 1961 (watch CIVIL ENGINEERING and this Newsletter for order forms). The coverage of the manual may best be illustrated by references to the table of contents. Chapter I, Introduction, discusses the development of ground water hydrology, the place of ground water in the hydrologic cycle, the importance of ground water, and outlines the major problems encountered in the development of subsurface water supplies. Chapter II, Outline of Ground Water Hydrology, covers the physical composition of ground water basins, the occurrence and movement of ground water, the characteristics of ground water reservoirs, and outlines methods of investigating the feasibility of ground water development. Chapter III, Calculation of the Perennial Supply, discusses the hydrologic equation and the various methods of determining the yield to be expected from the development of ground water.

Chapter IV, Recharge and Withdrawal, presents, for almost the first time in the literature, data and criteria for planning and operating artificial recharge projects and concludes with an extensive discussion of methods of planning for the extraction of water from underground reservoirs. Chapter V, Maintenance of Ground Water Quality, generally reviews the water quality requirements for various uses, waste disposal considerations, the effect of various physical influences on water quality, and concludes with a discussion of water pollution control legislation. Chapter VI, Planned Utilization of Ground Water, presents a considerable body of background material in legal and planning considerations, as they are related to the development of ground water supplies. Two appendices, one a sizeable list of selected references on the general subject of ground water, and the other, a presentation of recent or current research on artificial recharge, complete the text of the manual.

* * * * *

NEWS BRIEFS

The Utah legislature has authorized a Utah Water Research Laboratory to be constructed at Logan, Utah in connection with Utah State University. The authorization is for $1,250,000; it is expected that funds will be allotted for construction during this biennium.

Dr. O. W. Israelson, former member of the executive Board and of numerous committees, is lecturing at Lahore, Pakistan in an in-service training program sponsored by ICA. He will lecture at the SEATO Graduate School of Engineering in Bangkok this winter.

ASCE-WPCF JOINT SEWER MANUAL ISSUED

A major addition to the ASCE series of Manuals of Engineering Practice is now available in a new volume entitled "Design and Construction of Sanitary and Storm Sewers." Identified as No. 37, this publication is the result of several years of joint effort by the Sanitary Engineering Division of ASCE and the Water Pollution Control Federation (formerly the Federation of Sewage and Industrial Wastes Associations).

The twelve-chapter sewer manual contains 283 pages, over 100 illustrations, 24 tables, and more than 100 references. As the first extended collection of information on the subject, it will make a valuable reference in an important phase of wastewater technology. Individual subjects covered include organization and administration of sewer projects, surveys and investigations, quantity of sanitary sewage and storm water, hydraulics of sewers, design of sewer systems, appurtenances and special structures, materials for sewer construction, structural requirements, construction plans and specifications, construction methods, and pumping stations.

The manual may be ordered with the coupon herewith. The list price is $7.00 per copy. However, ASCE members may order the manual for $3.50 per copy. The price to members of the Water Pollution Control Federation is the same upon application to their organization.

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For complete coverage of the Society's 1959 year in print, there is now a Combined Index covering the Division Journals, Transactions, and Civil Engineering. Also included are reprints of the Proceedings Abstracts that are published each month in Civil Engineering. The price of the Combined Index (ASCE publication 1960-10) is $2.00 with the usual 50% discount to members. The coupon herewith will make ordering easy:

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Proceedings of the American Society of Civil Engineers

NEWS

November, 1960

LOS ANGELES PIPELINE GROUP

The monthly meeting of the Pipeline Group was held Thursday, February 25, 1960, at the Redwood House, 234 West First Street, Los Angeles. The social hour preceding the 7 p.m. dinner was sponsored by Southern Pipe and Casing Company. Sixty-three members and guests were present at the dinner hour.

The business session preceded the speakers and was conducted by Chairman, Jack Pierce. The Pipeline Group will sponsor the March General Meeting of the Los Angeles Section. This combined meeting will be the March meeting for the Group.

Program: Design of Cathodic Protection Systems and Practical Applications. More and more in today's pipeline work, the problem of cathodic protection becomes increasingly complicated. Both the proper design of a system and its practical installation are becoming a regular procedure to be incorporated in the over-all design and installation of underground piping systems of all kinds. The speakers are both recognized experts in the field of cathodic protection.

The first speaker, Mel Schiff, Consulting Engineer, presented a comprehensive discussion of the theory of corrosion and the design of cathodic protection systems. Don N. Miller of Southern Pacific Pipe Lines, Inc., then presented the practical installation phase of this protection. Mr. Miller's discussion included several references to actual experiences with both protection and interference.

The interest of the group in the subject of Cathodic Protection was shown both by the fine attendance and the lively question and answer period following the prepared portion of the program. The meeting was adjourned about 10:00 p.m.

The Pipeline Group, for their March meeting sponsored the General Meeting of the Los Angeles Section. The meeting was held March 9, 1960, in the Regal Room of the Carolina Pines Banquet Hall, 7315 Melrose Avenue.

This meeting fulfilled the requirement of six scheduled meetings of the Los Angeles Pipeline Group, thereby making this the first local Technical Group in the Society's Pipeline Division. The five previous meetings were held June 17, September 2, October 27, 1959, January 26, and February 25, 1960.

All portions of the meeting except the program were administered by the Local Section. Chairman Jack Pierce of the Pipeline Group presided over the program. H. J. Chapton, the National Committee member who was instrumental in organizing the local group introduced the speaker of the evening. Mr. William H. Kinne, Assistant to the Vice President in Charge of Operations, Kaiser Steel Corporation, spoke in the absence of Mr. G. B. McMeans, Vice President of Operations. Mr. McMeans was on a business trip to India. The subject of the evening, "Basic Oxygen Steel Making at Fontana," was interestingly presented in words, slides and movies. Several questions were answered by the speaker as the audience of about 100 members and guests showed their interest in this new steel making process.

The April meeting of the Pipeline Group took place on Thursday, the 28th at the Engineers' Club, Biltmore Hotel. The social hour prior to the 7:00 p.m. dinner was sponsored by Pipe Linings, Inc., and American Pipe and Construction Co. The meeting was attended by 58 members and guests.

Program: Design of Water, Oil and Gas Transmission Pipelines

Speakers: Mr. Maurice E. Fuller, Pacific Lighting Gas Supply Company; Mr. Munson Dowd, Metropolitan Water District of Southern California; and Benjamin F. Cuffey, Vice-President of Engineering, Sesler and Associates.

The three speakers, one each from a water, oil and gas pipeline company, reviewed the basic assumptions and design criteria for the design of a transmission pipeline in their respective areas. Since most pipeline engineer's experience is limited to one or possibly two types of pipeline designs, this symposium provided knowledge of the requirements of other pipeline industries. A brief discussion of the various pipeline codes as related to design of transmission pipelines was included by the first speaker.

The Pipeline Group's May meeting was held on Tuesday the 24th at the Engineer's Club, Biltmore Hotel. The social hour was sponsored by the Consolidated Western Steel Co. Dinner was served to 55 members and guests with several additional persons in attendance for the program portion.

Program: Contractor's Viewpoint - Construction of Large Transmission Pipelines

Speaker: Mr. M. B. Laulhere, President, Hood Construction Company

The construction phase of pipeline work was the next logical and concluding step in the series of subjects discussed at previous meetings. Mr. Laulhere is a contractor with a long and varied experience in the construction of major transmission pipelines of all kinds. The meeting provided all pipeline engineers an opportunity to become exposed to the contractor's side of pipeline construction. The program was presented in three parts: (1) General Observations about contracts, bids, specifications, inspection, etc. (2) Estimating ideas including a typical summary sheet as used by Hood Construction Co. (3) A movie on outstanding pipeline construction prepared by Caterpillar Tractor Co. Several questions from the audience were answered by the speaker.

TASK COMMITTEE ON PIPE LINE LOCATION

On June 21, 1960 this Committee met in Reno, Nevada. In attendance were: E. O. Scott, Chairman; R. H. Dodds, J. C. Faulkner, J. F. Schaffer. The committee reviewed its previous work and made recommendations to further its efforts.

A special appeal was made by Chairman Scott to all committee members to complete acquisition of material and bring to the next meeting. The Committee agreed to hold three (3) meetings between October 1, 1960 and September 30, 1961. The first to be in Kansas City area in October, in Phoenix during the April meeting, and in Denver during July 1961.

PIPELINE DIVISION NEW ORLEANS DIVISION MARCH 7-11, 1960

The following program was presented to the members during the New Orleans meeting. Officiating was Mr. F. C. Culpepper, who is Chairman of the Executive Committee. Mr. W. E. Matthews of Southern Natural Gas Company presented a paper entitled "Remote Control of Off-Shore Compressors by Microwave". The unique problems of right-of-way acquisitions in the Southern Louisiana area were reviewed by Mr. B. J. Whitley of Tennessee Gas Transmission Company. Mr. Edward McNamara of Freeport Sulfur Company presented a paper involving the construction of an underwater hot sulfur pipeline

During the afternoon session on March 7th, Mr. Don E. Adams of the Hallen Construction Co., Inc. presented Mr. Edward Doremus of the Cathodic Protection Service Company who stated his views on "Corrosion Control of Marine Pipelines". He was followed by Mr. Donald Simpson of Shell Pipe Line Corporation who outlined the "Construction Procedures Employed on the Delta Pipeline".

On Tuesday, March 8th, a tour of the pipe coating yards of H. C. Price Co. in Harvey, Louisiana, was made. The host gave various demonstrations of Hevicote concrete application ot 30'' pipe; Somastic coating to pipe for a Mississippi River Crossing; and of a 30'' pipe to be used in a swamp. Additional demonstrations were given by the Pipe Company of their steel shop blasting equipment, somastic priming equipment, plus a general tour of the coating yard.

All members were guests of the H. C. Price Company, later served at the plant. A vote of thanks is in order to Mr. Fred C. Culpepper and his committee who made the arrangements for this trip.

On Wednesday afternoon Mr. D. Williams Jr. presented Mr. Raymond H. Crowe of Transcontinental Gas Company who presented a paper relating to the "Bouyancy of Marine Pipelines". He was followed by Mr. Leo Odum who discussed the "design of Pipelines affected by various Mississippi River Crossings". Mr. M. Fitzpatrick outlined the Clear Span Method of Pipeline Crossings During the Concluding Operation. In general, the meeting was most informative and well attended.

TASK COMMITTEE ON FLOTATION STUDIES

On March 6th, 1960 this Task Committee met in New Orleans, Louisiana. In attendance were:

Chairman R. A. Rait ASCE - Humble Oil & Refining Co., Houston, Texas
J. J. Ball - Texas Eastern Transmission Corp., Shreveport, Louisiana
R. J. Brown ASCE - Collins Construction Co., Port Lavaca, Texas
W. G. Creel - H. C. Price Company, Harvey, Louisiana
L. K. Croker - Allan Edwards, Inc., Tulsa, Oklahoma
W. L. Hollander ASCE - A. B. Chance Company, Centralia, Missouri

E. C. Kirchner ASCE - American Louisiana Pipe Line Co., Detroit, Mich.
R. E. Kling ASCE - Smith-Cooke Construction Co., St. Louis, Missouri
E. H. Lamar - United Gas Pipe Line Company, Shreveport, Louisiana
H. H. List ASCE - Shell Pipe Line Company, Houston, Texas
Alex Mackie - A. B. Chance Company, Centralia, Missouri
J. H. Norris ASCE - Southern Natural Gas Co., Birmingham, Alabama
J. B. Spangler ASCE - Transcontinental Gas Pipe Line Corp., Houston, Texas
J. H. Spracklen ASCE - Transcontinental Gas Pipe Line Corp., Houston, Texas
Chairman, Pipeline Division, Executive Committee, F. C. Culpepper ASCE - Ford, Bacon & Davis, Inc., Monroe, Louisiana
Board Contact Member J. E. Rinne ASCE - Standard Oil Co. of California, San Francisco, California
Assistant Secretary D. P. Reynolds ASCE -Headquarters of the Society New York, New York

After a review of the minutes of the last February 4th meeting, discussions and actions taken are briefly summarized:

1. Chairman Rail reported that a letter dated February 26th had been sent to the Bureau of Engineering Research of the University of Texas as follows:

"At a meeting of the control group of the Task Committee on Pipeline Flotation in Houston on February 26, 1960, it was decided that this committee would undertake to prepare a paper or statement outlining the objectives of the committee and the status of our knowledge in regard to pipeline flotation. It was also decided that any attempt at research to improve our knowledge on this subject should advantageously be postponed until such time as this document is completed to the satisfaction of the entire committee. While it is not our wish to decline your proposal, it is uncertain at this time as to when we will be in a position to proceed with a definite research program. In view of the foregoing, it appears that our initial invitation to you to submit a proposal on this research was somewhat premature. We do wish to express our appreciation for the time and consideration you have given the matter up to this point."

2. Chairman Rait also reported that an outline for a paper or statement outlining the objectives of the committee and status of our knowledge had been prepared. Committee members will be assigned to prepare portions of the text indicated in this outline for review and editing by the Chairman prior to submission as a progress report to be published in the Pipeline Division Journal in accordance with manual instructions in the ASCE "Technical Publications Handbook".

Various sub-committee reports were held detailing some of the investigations that have been made. Of interest to our members were the comments on financing, which was discussed with Mr. D. P. Reynolds and J. E. Rinne. Reynolds advised that Engineering Foundation no longer furnishes "seed" money for ASCE research. In obtaining approvals by the Pipeline Division Executive Committee and the Committee on Division Activities of investigations originated by our Task Committee, we should furnish a good description and define the project as one to fine new information. Funds should be raised by the Task Committee and Reynolds advised that we should

use informal procedures by having grants go direct to our selected agent or agents and not through the ASCE, any research committee, or research council. This is a reversal of advice previously received from Reynolds by letter dated January 21, 1960.

Of particular interest to our members of the Pipeline Division will be the recommendation given to the Los Angeles Pipeline Corporation by "The Engineering of Southern California", In the March issue. This publication outlined the meeting held on March 9th. The guest speaker for the occasion was Mr. George B. McNamara, Vice President of Operations, Kaiser Steel Corp., who discussed "Basic Oxygen Steel Making".

In addition, we offer our congratulations to the Los Angeles Section as their local pipeline committee recently became a full-fledged group, and now enjoys the same status as the other local technical groups.

The attendance at these meetings has been running very high and averaging 70 members. The work of those officials is certainly worthy of note.

PIPELINE PLANNING COMMITTEE

A meeting of this Committee was convened at 9:00 a.m. on May 23, 1960, at the Adolphus Hotel in Dallas, Texas. Those present were:

Carter L. Shea - Chairman
Lewis E. Hoffman - Control Group Member
Mercel J. Shelton - Control Group Member
C. W. E. Davies
Jack W. Pierce
Frank J. Stastny

Task Committee Reports

Reports from the various Task Committees were received and discussed as follows:

(1) Committee on Investigation of Governmental Regulation of Pipeline Design and Construction

Chairman L E Hoffman reported that this Task Committee has substantially completed the first phase of its assigned task which involved the investigation of existing codes and a determination as to whether significant problem areas exist as a result of conflicting or unduly restrictive requirements. Two interim reports have been published in the Pipeline Division Journal which have listed existing codes and itemized specific variations from the requirements of ASA Code B31.1.

As a result of Committee activities to date and in the light of various discussions and comments evoked by the published reports, it is the Task Committee's view that a major problem area exists in the increasing tendency of the various state regulating bodies to adopt code requirements which, altho based on ASA B31.1, contain unduly restrictive additional provisions which materially increase the cost of pipeline construction and appears to be of doubtful value in regard to protecting the interests and safety of the public.

It was agreed that a proposal would be submitted through ASCE channels that a joint conference be arranged with representatives of ASA, ASME

and other interested organizations to explore the possibility of organizing an active group to promote uniformity in code requirements by sponsoring the general adoption of ASA B31.1 with a minimum of charges or additions.

The Task Committee will remain active until definite action is taken on this proposal:

(2) Committee on Compilation of a Bibliography

Chairman M. J. Shelton reported that a supplemental report is being submitted by this group which will list additional materials and will correct various minor errors included in the listing which was published in the October 1959 issue of the Pipeline Division Journal. It was agreed that, with the publication of this supplemental report, this Task Committee will have substantially completed its original assignment. Accordingly, a recommendation will be made to the Executive Committee that this group be discharged effective at the end of the current fiscal year, in October 1960. A review of the published bibliography will be made at three year intervals by the Committee on Pipeline Planning, and, when indicated, a supplemental listing will be prepared by a new Task Committee.

It was noted that no formal discussion or comment was received by this Task Committee following the publication of the initial bibliography in October 1959. The Task Committee expressed the opinion that additional stimulation of interest at the Local Section level would be desirable in order to generate greater interest and participation in discussions of technical papers published in the Pipeline Division Journal. Mr. Shelton presented a rough draft of a proposed letter to be sent over the signature of the Executive Secretary of the ASCE to all Local Sections in regard to generating increased participation in the discussion of technical papers. After some discussion, it was agreed that this proposal would be expanded to include reference to the several reports published by the "Task Committee on Governmental Regulations" and forwarded to the Executive Committee of the Pipeline Division for further consideration.

(3) Committee on Investigation of Economic Aspects of Mitigating Pipeline Corrosion

Chairman J. W. Pierce presented a discussion of several proposed steps in the recruitment of personnel for this group as well as the development of a plan for specific committee activities.

After considerable discussion, it was agreed that the proposed scope of the Committee's activities should be more clearly defined and that the title should be modified to that shown above.

The following was adopted as the scope of this Task Committee's Activities:

"To investigate and disseminate to the profession information relative to the economic considerations involved in the selection of external pipeline coatings and the application of cathodic protection systems on new and existing pipelines. This includes consideration of the use of high strength, "thin-wall" pipe and the determination of operating pressures on existing pipelines which have suffered corrosive deteriorations."

Various methods of recruiting personnel for assignment to this Committee were discussed and it was agreed that Mr. Pierce will submit his nominations for membership in the "Control Group" directly to the Executive Committee of the Pipeline Division. Committee members who are interested in participating with this group are requested to contact Mr. Pierce at the following address:

Mr. J. W. Pierce
Supervisory Design Engineer
Southern California Gas Co.
P. O. Box 3249, Terminal Annex
Los Angeles, California

After the selection of Task Committee personnel has been completed, this group will prepare a questionaire to be circulated to various operating companies in order to determinė current practices in this field and to establish areas of agreement as well as to define areas of uncertainty.

Personnel

It was agreed that, consistent with basic ASCE policy, a program should be established to provide for the orderly rotation of personnel into the administrative group of the Committee on Pipeline Planning and to stimulate the participation of new membership in the Committee "Control Group".

Accordingly, the following actions were agreed upon and are hereby recommended to the Executive Committee of the Pipeline Division for formal approval:

(1) C. L. Shea - will complete a four year term as Chairman in October 1960 and will be replaced in this office by J. B. Spangler. Mr. Spangler was contacted during the meeting and indicated his availability to serve in this assignment.

(2) L. E. Hoffmann - will be assigned as Vice-Chairman and Control Group member effective October 1960.

(3) C. W. E. Davies - will be assigned as a Control Group member, effective immediately to fill the vacancy which exists as the result of the withdrawal of D. R. Jenkins from this post.

(4) J. A. Shaw - will be assigned as a Control Group member, effective October 1960, replacing C. L. Shea.

To summarize these changes, the Committee Control Group now consists of the following:

C. L. Shea - Chairman
L. E. Hoffmann
M. J. Shelton
J. B. Spangler
C. W. E. Davies

Effective October 1, 1960 (start of fiscal year):

J. B. Spangler - Chairman
L. E. Hoffmann - Vice President
M. J. Shelton
C. W. E. Davies
J. A. Shaw

As of October 1, 1960, C. L. Shea will be assigned as a Control Group member of the Task Committee on "Investigation of Governmental

Regulations" and will continue to participate as a member of the Committee on Pipeline Planning.

General

It was agreed that two meetings would be scheduled for the next fiscal year and that tentatively the next meeting would be scheduled for November 1960 at St. Louis, Missouri.

From Jack Pierce, Chairman, Pipeline Group, Los Angeles Section, the Newsletter recently received some basic thoughts for those interested in forming an effective local pipeline group. His basic concepts provide an excellent basis for action.

1. There should be a considerable amount of pipeline activity in the area. It is desirable that the local group include engineers working in most of or all of the following types of pipeline work: (a) flood control storm drains, (b) water lines, (c) gas lines, (d) oil lines, (e) sewer lines, and (f) product lines.
2. Engineers involved in all phases of engineering should be encouraged to participate. This includes design engineers and construction engineers as well as sales engineers (from the local pipe companies). Participation should cover off on all types of piping materials including steel and concrete.
3. It is very advantageous to have a strong and well accepted pipeline engineer as chairman of the group and another of comparable stature as program chairman.
4. When the first or formative meeting is called, every effort should be made to obtain as wide a publicity coverage as possible.
5. One of the key considerations in starting off successfully and yet one of the most difficult to fill is the selection of an adequate meeting place with the following desirable characteristics: (a) well located, (b) good facilities for holding meetings (availability of projectors, screens, public address system), (c) at least adequate food, (d) dinners should be reasonably priced, and (e) since the social aspects are very important, there should be facilities available for a friendship or social period before the meeting.
6. In order to maintain continued interest, it is suggested that meetings be set up on a montly basis except for the Summer. Seven to eight good meetings a year would be about right. If the group can get off to a good start, regular meeting trends or habits can be established by the pipeline engineers in the area.
7. Another key consideration is the setting up of an overall yearly program theme, then fitting the monthly programs into this theme in proper sequence. As an example, the Los Angeles Section Pipeline Group set up a theme of carrying various types of pipeline consideration through from design to installation. The sequence could have been improved but by and large the theme was covered off fairly well. The actual program schedule consisted of: (a) Summary of a large gas pipeline construction project, (b) Symposium on steel pipe coating by sales engineers, (c) Symposium on the effectiveness of steel pipe coating by pipeline design engineers, (d) Design of cathodic protection systems and their practical applications, (e) Design of large water, oil and gas transmission pipelines, (f) Contractors viewpoint—construction of large transmission pipelines, (g) Physical and stress

considerations of high strength large diameter, steel pipelines, and (h) The construction Engineer's viewpoint—construction of large diameter concrete pipelines.

Should any additional information be required on the formation of the Los Angeles group, Jack would be glad to oblige.

The cooperation of all members is needed to provide the Newsletter with articles of interest in order to make it a regular and timely publication. Please submit your articles to:

J. H. Mitchell
Vice President
Lockwood, Kessler & Bartlett, Inc.
One Aerial Way
Syosset, New York

NEW DIRECTORY IS AVAILABLE TO MEMBERS

The 1960 Directory is now available to members on request. The Directory lists the entire membership of the Society, giving the membership grade, position, and mailing address of each. In addition, there is a complete listing of the Honorary Members, past and present, and the Life Members. A useful geographical listing of the members is also included.

It goes without saying that the information contained in the Directory is of value to every member, and every member can obtain this valuable information. To receive your free copy of the Directory simply fill out the coupon below. Prompt delivery depends on prompt return of the coupon.

The Society publishes the membership Directory every other year. The next edition will be issued in 1962.

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